DISSERTATION

Simulation-supported Design Optimisation for Lifecycle-oriented Buildings

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Doktors der Technischen Wissenschaften unter der Leitung von

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KURZFASSUNG

Ein verhältnismäßig großer Anteil des Energie- und Ressourcenverbrauches fällt im Gebäudebereich an. Das betrifft die Herstellung von Baustoffen, die Errichtung von Gebäuden und in weiterer Folge den Energieverbrauch innerhalb der Gebäude durch die NutzerInnen. Eine Designoptimierung von lebenszyklusorientierten Gebäuden soll dazu beitragen den Energie- und Ressourcenverbrauch im Gebäudebereich in Österreich zu verringern.

Die Studie *Simulationsunterstützte Designoptimierung Lebenszyklusorientierter Gebäude* (Sim4DLG, FFG 853842) zielt darauf ab durch die Einbindung dynamischer Simulationen eine Reduzierung des Energieverbrauches sowie des Überhitzungsrisikos sowohl in der kalten wie auch in der warmen Jahreszeit zu erreichen als auch die Planungsabläufe selbst zu verbessern. Ergänzend zum Heizwärmebedarf der Gebäude wird auch das Innenraumklima insbesondere über die Innentemperaturen untersucht um das Überhitzungsrisiko dieser Gebäude zu vermeiden und den thermischen Komfort der NutzerInnen zu erhöhen.

Diese Methodik wird für eine Auswahl verschiedener Gebäudetypen entlang den Planungsphasen der Entwurfsplanung, der Einreichplanung und der Detailplanung bis zum finalen Gebäudedesign angewandt. Die Gebäudetypen variieren von Einfamilienhäusern bis hin zu Reihenhäusern und Wohnungen in einem mehrgeschossigen Gebäudeverbund, welche im Rahmen des Projektes *Life Cycle Habitation* (LIFE ENV/AT/000741) errichtet werden und als Fallbeispiele dienen.

Der Fokus der Optimierungen in dieser Studie liegt auf dem architektonischen Design der Gebäude wie der Geometrie, der transparenten und opaken Flächen oder dem Verschattungskonzept. Ergänzend werden Szenarien der natürlichen Belüftung für eine Verbesserung des thermischen Komforts in der Sommerzeit untersucht.

Die Studie zeigt auf, dass durch die Integration von dynamischen Simulationen in den Planungsprozess abhängig von der Wahl der Parameter eine Optimierung der gewünschten technischen, ökologischen oder ökonomischen Gebäudeaspekte erreicht werden kann. Präzise dimensionierte Gebäudeparameter und ein akkurates Design in Kombination mit natürlicher Belüftung ermöglichen eine deutliche Verbesserung des Innenraumklimas und des thermischen Komforts bei einer gleichzeitigen Aufrechterhaltung des Passivhausstandards entsprechend dem österreichischen Energieausweis.

Keywords

Heizwärmebedarf, dynamische Simulation, Energieeffizienz, nachhaltige Gebäude, Überhitzungsrisiko

ABSTRACT

A relatively large percentage of energy and resource consumption occurs in the building sector. This concerns the production of building materials, the construction of buildings and also the energy consumption during the use phase. To reduce the energy and resource consumption in the building sector, this study conducted within the project *Simulation-supported Design Optimisation for Lifecycle-oriented Buildings* (Sim4DLG FFG 853842) is focusing on a design optimisation of life cycle oriented buildings in Austria.

To reduce the heating demand and overheating risk in the cold and warm seasons respectively, a simulation-supported optimisation strategy is pursued, together with an improvement of the planning processes themselves.

This approach is applied to a range of different building types along the three major planning phases of the design process, the early design stage, the final planning permit design stage and the final building design stage. The building types are varying from stand-alone single family houses to townhouses and apartments in a multi-storey building, which are to be constructed within the project *Life Cycle Habitation* (LIFE13 ENV/AT/000741). Apart from the heating demand of the buildings, the indoor environment in view of the indoor temperatures are specifically examined to avoid overheating risk and to increase the thermal comfort for the occupants.

The focus for the optimisation lies on the architectural design parameters like the building geometry, the opaque and transparent surfaces as well as the shading design. Natural ventilation scenarios are specifically explored to improve summertime thermal comfort conditions.

The study reveals that the integration of dynamic simulations in the design process of buildings can lead to an optimisation of the desired technical, ecological or economic aspects depending on the choice of building parameters.

The results suggest that properly dimensioned building parameters and an accurate design especially in combination with natural ventilation can improve the indoor temperatures and also the thermal comfort of the occupants significantly, while maintaining the passive house standard according to the Austrian energy certificate.

Keywords

Heating demand, dynamic simulation, energy-efficiency, sustainable building, overheating risk

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This work is dedicated to Nefeli.

CONTENTS

1 INTRODUCTION

1.1 Motivation

A relatively large percentage of energy and resource consumption occurs in the building sector (European Union, 2010). This concerns the production of building materials, the construction of buildings and also the energy consumption during the use phase.

With its high consumption of energy and thus mostly fossil fuels for the majority of processes, the building sector is with 10 % in Austria also one of the largest perpetrators of carbon dioxide (CO_2) emissions (Environment Agency Austria, 2016).

The demand for improvements, new strategies and alternative solutions in the field of construction is also stated by the concluded Paris Agreement in 2015 with the goal of a global average temperature increase of below 2 Kelvin (K) above preindustrial level in context with the alarming greenhouse gas emissions (United Nations, 2015).

Moreover, during the lifecycle of buildings additional energy and resource consumption results from demolition and disposal of buildings or building parts at the end of their lifetime.

To encounter this demand, this work aims at reducing the energy consumption through a design optimisation of lifecycle-oriented buildings and an improvement of the planning processes themselves by using dynamic simulations in addition to the mandatory energy performance certificate (EPC) in Austria.

1.2 Background

Building optimisation has been an area of research for a number of years with growing interest, which is also caused by the recast of the European Performance of Buildings Directive (EPBD) and its energy-efficiency target (European Union, 2018) together with national standards like the OIB 6 (Austrian Institute of Construction Engineering, OIB Guideline 6 - Energy saving and heat insulation, OIB-330.6-026/19, 2019) of the Austrian Institute of Construction Engineering (OIB). Due to increased targets towards nearly zero energy buildings (nZEB) also the building performance simulation becomes more demanding and challenging because of a complexity of measures for reducing the energy use of buildings. Building performance simulation tools became therefore a fundamental way to assist in the decision making process for energy efficient building designs (Attia, Hensen, Beltran, & De Herde, 2012).

To develop such an environment-friendly and energy conscious building design, a combination of a number of parameters have to be considered rather than individual ones (Shaviv, 1999). The parameters should be covering the full spectrum of buildings from the structure (e.g. orientation, geometry, layout) with its external envelope including walls (e.g. constructions and materials), windows (e.g. size, position and glass type) and shading elements to its HVAC and lighting systems to mention some.

The use of building simulation tools is thus also a challenging one considering the number of available tools, which are often used in different design stages, because of limited applicability for such advanced buildings. Not to forget that there is no established design strategy to systematically achieve the goal of an energy-efficient and ecological building design (Athienitis, et al., 2010).

Furthermore, the majority of building optimisation studies (59 %) are applied in the early design stage (Athienitis, et al., 2010), in which most design decisions have to be made, but also the application in later design stages are likewise highly recommended to finalise the structural design and the building operation (Attia, Hamdy, O´Brien, & Carlucci, 2013).

To successfully design an energy-efficient building with a low environmental impact an overall design process starting with a predesign stage and finishing in a post-occupancy evaluation is suggested, in which the entire team of architects and engineers is pursuing early established high energy targets (Hayter, Torcellini, Hayter, & Judkoff, 2001).

But evaluating many different design options during the various design stages is a time-consuming matter, while there is in contrary a high demand for a faster modelling and more automated optimisation processes to achieve building solutions with desirable qualities (Zhang, et al., 2013).

1.3 Structure of the thesis

This thesis is divided into five chapters. The 1st chapter explains the motivation for this study, gives some background information on design optimisations of energy-efficient and ecological building concepts, and provides a short overview. The 2nd chapter outlines the research objectives, describes the applied methods to approach these and presents the case study objects used for this work. The 3rd chapter shows the results achieved for the three major stages of the design process: The early design stage, the detailed planning permit design stage and the final building design stage. The 4th chapter discusses the results, while the 5th and last chapter draws conclusion on the study´s results and points out the outlook of future tasks.

2 METHOD

The research questions have been elaborated in the first part of this thesis in order to clarify the purpose of this work (see chapter 2.1). The background of the project including the envisaged overall design of the buildings, the location and climate is delineated in the second part of this chapter as well as the general cooperation network and workflow of the involved stakeholder outlined (see chapter 2.2).

In the third part of this chapter, the building design optimisation process is presented (see chapter 2.3), subdivided into the early design stage, the detailed planning permit stage and the final building design stage. The methods applied in each design stage are described in detail in the respective subchapters. The optimised building models are then also verified with the results of the mandatory Austrian EPC.

In the last parts of this chapter the requirements regarding the prevention of summerly overheating according to the Austrian standards are provided (see chapter 2.4) and the used evaluation practices for the ecological assessment specified (see chapter 2.5).

2.1 Research Questions

The thesis is aiming at the development and optimisation of building concepts by concentrating at a reduction of the energy consumption towards energy-self-sufficiency of different building types due to the use of dynamic simulations. It investigates to what extend the technical, ecological and economic perspective of lifecycle-oriented buildings can be optimised compared to conventional static calculations. Simultaneously it aims to fulfil the criteria regarding thermal comfort. In addition, the transferability of the designed concepts and strategies for other locations with different climatic criteria in Austria is being investigated.

To target the research objectives already outlined, the study is addressing the following research questions:

- Arguably the project´s target is the reduction of energy consumption due to dynamic simulations. Which **optimisation method** is especially suitable for a certain major planning stage or **design process**?
- Can dynamic simulations in the course of the planning of a building, in addition to the mandatory Austrian EPC, lead to a reduction of the **heating demand**?
- Can the **thermal comfort** of the occupants be maintained or even increased at the same time?

- Are the optimised building designs **transferable** and therefore suitable for other locations in Austria with varying climate conditions?

This thesis is part of an innovative building project (see chapter 2.2), which is targeting the demonstration of energy-efficient, **ecological building designs** by use of locally available, renewable building materials and **cost-efficient constructions**. Therefore, the overall project's **planning procedure, cooperation network and workflow** are implemented. As a further aim of the thesis, the documentation of the integration of dynamic simulations should lead to findings for a better and more dynamic completion of future planning processes.

2.2 Building project

The thesis was carried out within the project *Simulationsunterstützte Designoptimierung Lebenszyklus orientierter Gebäude* (SIM4DLG) and applied to the case study buildings (Sim4DLG Information website, 2018) realised within in the framework of the EU (European Union) Life project *LIFE Cycle Habitation* (LCH). The latter is targeting the demonstration of innovative building concepts that significantly reduce CO_2 emissions, mitigate climate change and contain a minimum of grey energy over their entire lifecycle with the goal to make energy-efficient settlements the standard of tomorrow in line with the EU 2020 objectives (Life Cycle Habitation project homepage, 2018). To this end, a highly resource and energy-efficient building compound is being built in Böheimkirchen, Lower Austria.

As shown in the preliminary draft and the site plan of the case study project (Figure 1), LCH consists of a building compound, which includes 6 living units and a community area (CA), as well as 2 single-family houses. In total building units with a usable floor surface of approximately 710 m² including the CA, will be constructed in an optimised and energy-efficient way. The construction site itself is covering an area of 3674 m² including a green area of 552 m² at the eastern border. The building compound will be designed as a 2-storey non-load-bearing straw bale construction in style of the neighbouring award winning S-House (Wimmer, Hohensinner, Drack, & et. al., 2005). It includes 2 row houses with a usable floor space of 110 m² each and 4 apartments with sizes between 55 and 90 m². Both single-family houses, which have a usable floor space of approximately 110 m², will be realised as compact flat-roof buildings in a 1-storey atrium-style load-bearing straw bale construction.

Figure 1: Left: site plan; right: preliminary design of the buildings (Arch. Scheicher)

First the concept of the buildings is based on energy-efficient building solutions (passive house components, improved household appliances, thermal insulation etc.) and on the maximum utilisation of regional renewable resources for building materials to reach a lower energy demand in production as well as shorter transport distances.

Second, deconstruction is considered already from the planning process in order to promote recycling and composting after the use period. Compatible with this aim, straw as insulation material has a key role since it has been proven to be functional and show a very low primary energy input (PEI) as well as a positive effect for the CO_2 balance of the building (Krick, 2008). For this project 2 different types of wood-straw construction will be realised. The first variant, for the building compound, consists of prefabricated non-load-bearing straw bale modules, which will be attached to a wooden structure. The second variant, for the atrium houses, will be a load-bearing straw bale construction made of big bales with a plastered façade. Triple layer windows and an overhanging roof improve the performance of the building envelopes.

Third, the concept includes an innovative energy system based on locally available renewable energies for further reduction of the carbon footprint.

After completion of the project, the developed building concepts should then be used as template for the further extension of the settlement to the adjoining property at the northern border with a size of 7568 m² including a green area of 793 m².

2.2.1 Location and climate

The case study buildings are located in Böheimkirchen, Lower Austria. The exact coordinates of the construction site are latitude at 48.19°, longitude at 15.75° and an average altitude of 245 m.

Figure 2: Location of the project in Böheimkirchen, Lower Austria (google earth)

With average monthly air temperatures between 0.2 and 20.9 °C (degree Celsius) and average monthly relative humidities between 62 and 79 % Böheimkirchen has a temperate climate.

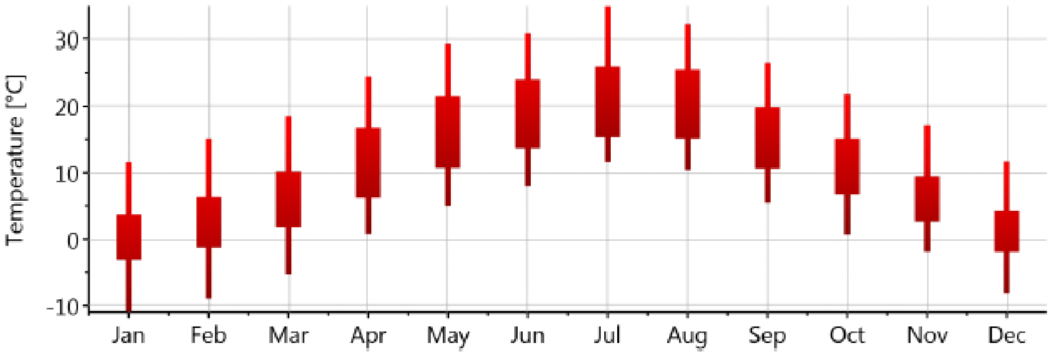

Figure 3: Average monthly temperatures for Böheimkirchen (Meteonorm, 2016)

According to the Köppen-Geiger classification the north-eastern region of Austria is categorised as Cfb (warm tempered humid climate) with the warmest month lower than 22 °C in average and four or more months above 10 °C in average (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). The annual precipitation is in total approximately 670 mm, while the monthly values are varying between 30 and 80 mm. The annual average mean irradiance of global radiation horizontal is 134 W/m² for Böheimkirchen according to the Meteonorm climate data.

2.2.2 Cooperation network and workflow

The project consortium consists of the research institution (GrAT – Center for Appropriate Technology), which is the project leader, together with two partners, an engineering office (teamgmi Ingenieurbüro GmbH) and an architect (Architekten Scheicher ZT GmbH). These three together are forming the project management team, which is in the centre of this cooperation network, and are mainly responsible for the planning processes and also the successful execution of the project in general. Technical experts of different domains support, if required, the management team. The building project itself is realised in cooperation with local small and medium enterprises (SME), which are typical for the Austrian building sector. Which is why the local production of the prefabricated building elements, the use of locally available resources and the reduction of transport distances is possible. This is not only beneficial for the overall project objectives of an environmental-friendly building project, but also for the regional value-added chain (Wimmer, et al., 2009).

The involved SME´s are organised, depending on their area of responsibility, their experience and the projects demand, in an efficient way in a combination of centralised and decentralised activities under the lead of a general contractor. An advantage of this concept is that all involved parties can work on the one side in their own area of competence with high quality, while they can compete on the other side with economic-based large enterprises.

The overall cooperation network is displayed in the following Figure 4, while the workflow of the different planning and optimisation stages are described in more detail in the respective subchapters.

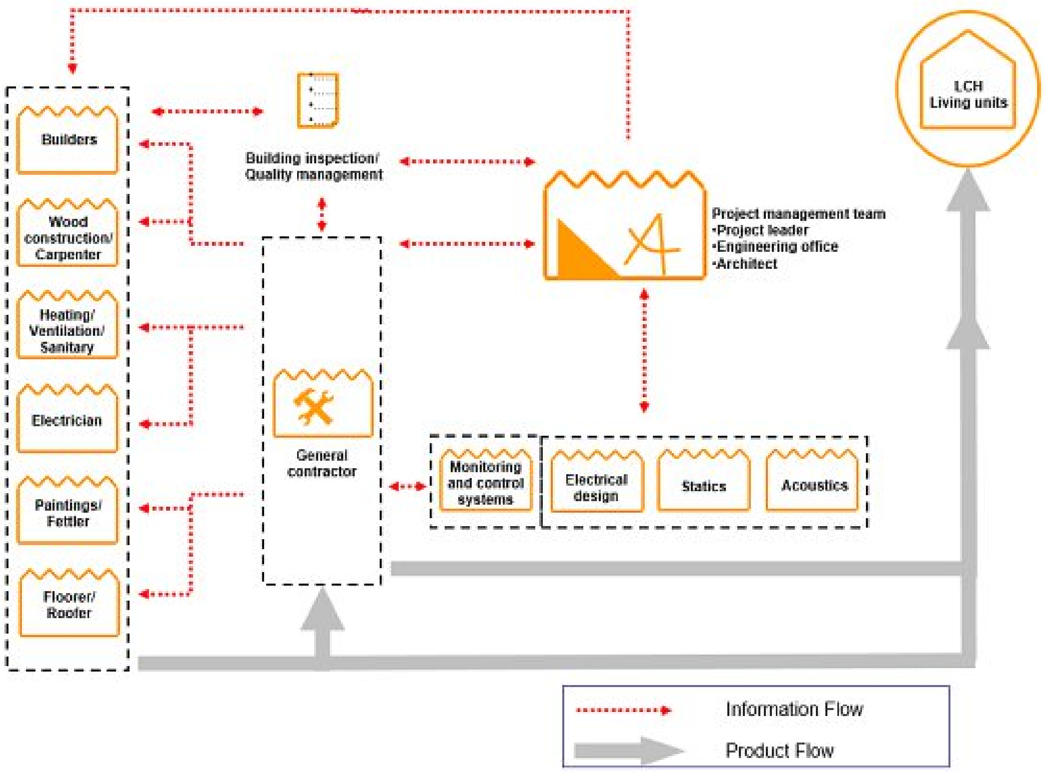

Figure 4: Overall workflow of the building project

2.3 Building design stages

In order to optimise the performance of the buildings and in consequence also to achieve improved results for the mandatory Austrian EPC, a simulation-based design optimisation approach is used for the buildings, in particular for their architectural design.

The overall optimisation process is divided into three major stages (see Figure 5) corresponding with the phases of the general design process of buildings and the required submission documents.

1. preliminary design or early design stage
2. detailed planning permit stage
3. final design stage

The pre-design stage (conceptual stage) as well as the post-planning stages (e. g. construction and post-occupancy evaluation) are not considered in this optimisation approach.

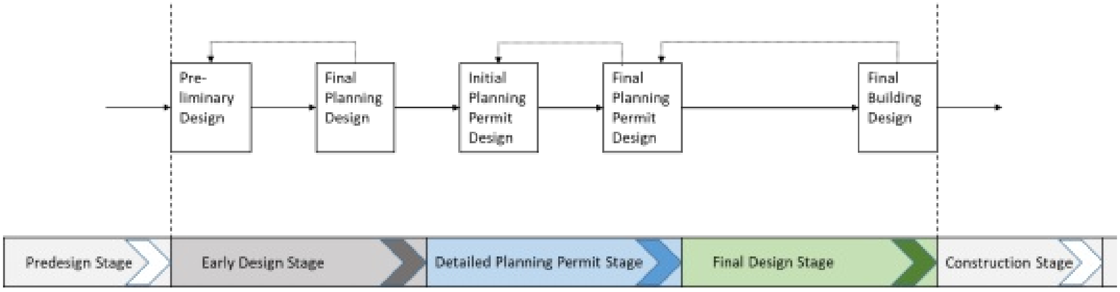

Figure 5: Optimisation process and system boundaries

The building optimisation with selected parameters can be applied in a linear or circular approach from a simplified to a detailed model for each stage of the design process, if required. The selected tools and parameters used for the different building types in each optimisation stage are described in more detail in the following subchapters.

2.3.1 Early design stage

In a first step a simulation-based rapid design approach is applied for the early design stage. In this phase the whole building simulation tool EnergyPlus (EP+) (EnergyPlus, 2018) by the U.S. Department of Energy is used in combination with SketchUp (SketchUp, 2018), Openstudio (OpenStudio, 2018) and GenOpt (GenOpt, 2018) for selected optimisation methods. For the execution of the concurrently calculated Austrian EPC the software GEQ by Zehentmayer Software GmbH is used (GEQ, 2018).

There is a variety of options how a building can be improved even with these preselected tools, but the biggest effects during the early design stage can be achieved in general by improving the building shape, the orientation of the building, the type of thermal insulation, the size and position of the transparent building elements as well as by appropriate shading (Attia, Gratia, De Herdea, & Hensen, 2012).

Methods like the Window-to-Wall Ratio (WWR), a parametric simulation with EP+ or a more detailed optimisation approach with GenOpt are integrated in this early design stage of the study.

<u>Window-to-Wall Ratio</u>

In the first applied optimisation method the general ratio of transparent to opaque building elements of the preliminary draft is analysed, as an optimised WWR can lead to a significant reduction of the annual energy demand (Goja, 2016). Surely, finding the optimal WWR value for a building surface depends on various variables, which are set during the design process, namely on the climate and orientation an optimised WWR.

Therefore, at this early design stage the sizes of the south and east oriented windows, which are facing the courtyard in case of the atrium-style buildings, can be optimised. A simple and easy-to-handle tool for the implementation is the Open Studio User Scripts Extension "Set Window-To-Wall Ratio", which can be used while creating the geometry of the building in SketchUp instead of drawing the windows manually.

For this method it has to be taken into account that the results in EP+ can differ, even if the transparent surface area is the same, due to varying solar gains caused by the diverging shape and arrangement of the fenestration surfaces. Such differences are shown in Figure 6.

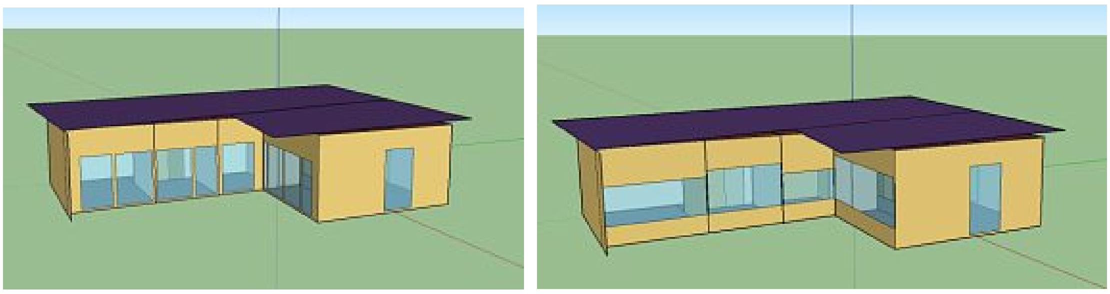

Figure 6: WWR application for the same transparent surface area: Left: preliminary design; right: WWR function

Orientation

In the second applied optimisation method the parametric modelling function of EP+ is used for identifying the optimal orientation of the current building model. The simulation can be performed for example with a clockwise rotation of a defined step starting from the north axis until a complete turn of 360°. If the simulation is to be compared with the EPC calculation, it has to be taken into account that the direction of the building can only be selected from a maximum of 16 points of the compass.

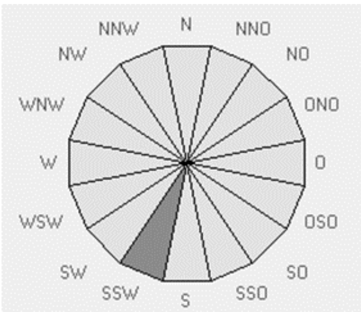

Figure 7: Selection for the orientation of transparent surfaces for the Austrian EPC (GEQ, 2018)

Detailed Window Optimisation

In the third applied method EP+ is used in combination with GenOpt for a detailed window optimisation to achieve a minimum heating and cooling demand for selected thermal zones of the building. This method can be used for example for improving the size and general position of the elements, but also for supporting the selection of materials and appropriate shading like an overhanging roof or the operation of a mechanical shading device (Wetter, 2000).

2.3.2 Detailed planning permit stage

Proceeding from the design planning phase and the results of the early stage optimisation, a design optimisation with a more detailed building model is implemented in this phase. A fundamental difference in this phase is that the focus is on 2 performance indicators (PI) instead of 1 compared to the prior phase. The first PI is the heating demand of the buildings, corresponding with the optimisation of the early design stage, but with the principally decision not to have any air conditioning systems in the buildings. The second PI is accordingly the overheating of the building. As these two key PIs are acting in opposing directions, a parametric optimisation approach with EP+ likewise in combination with SketchUp and Openstudio is used in order to achieve improved models suitable for the buildings. For the concurrently calculated Austrian EPC the software GEQ is used again.

The simulation models are defined based on standard assumptions according to calculation methods of the Austrian EPC with a standard heating set point (HSP) of 20 °C and a fixed air change rate (ACR) of 0.4 h^{-1}. According to the design of the buildings typical activities varying from sleeping to housecleaning in accordance with the ASHRAE standard are assumed for the occupants (ASHRAE HANDBOOK, 2005).

Due to an analysis and assessment of the indoor temperatures for each variant an overheating of the buildings should be avoided and the thermal comfort should be increased.

<u>Atrium buildings</u>

Continuing from the defined building shape and orientation, the main focus for the atrium-style buildings (see Figure 8 and chapter 3.2.1 for the detailed building parameter) in this phase is on the building envelope. Therefore important steps are the optimisation of the window dimensions and the shading elements of the overhanging roof, to find a balanced design solution for the two PIs, to achieve a building design with a low heating energy demand but also with a healthy and comfortable indoor environment (Vanhoutteghem, Skarning, Hviid, & Svendsen, 2015).

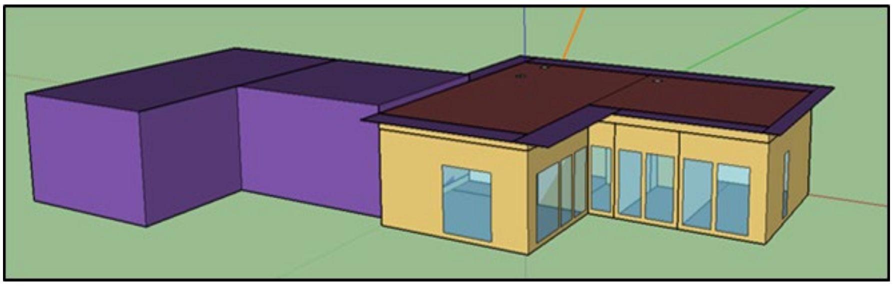

Figure 8: EP+ geometry model for the atrium-style building located to the east

The variables for the parametric optimisation of the windows are illustrated in Table 1. The windows facing the courtyard have fixed sizes because of structural reasons and are therefore excluded from the optimisation process. The windows in the northwest corner of the building should be replaced by solar tubes in the roof. An additional window in the northeast corner of the building is included in the simulations to examine the effect of a panoramic view of the surrounding countryside.

Table 1: Window width variables for parametric simulation

Building	**EH-NNE [m]**	**Bed1-NNE [m]**	**Bed1-EES [m]**	**LK-SSW [m]**	**LK-WWN [m]**
Atrium East	0.0-1.4	-	0.0-2.2	0.0-2.2	-
Atrium West	0.0-1.4	0.0-1.4	-	0.0-2.2	0.0-2.2

Table 2 is showing the parametric optimisation variables for the overhang of the roof. A more detailed step of 0.1 m is used for the overhang, while the window width is dependent on the grid of the load-bearing straw bales measuring 0.8 m.

Table 2: Overhang depth variables for parametric simulation

Building	**NNE [m]**	**EES-1 [m]**	**EES-2 [m]**	**SSW-1 [m]**	**SSW-2 [m]**
Atrium East	0.5-1.5	0.5-1.5	0.5-1.5	0.5-1.5	0.5-1.5
Atrium West	0.5-1.5	-	0.5-1.5	0.5-1.5	0.5-1.5

Building compound

For the optimisation of the building compound, three living units are investigated in detail during this phase. These are Top 2, Top 4 and Top 6, covering the town house style unit as well as one apartment in the ground floor (GF) and one in the upper floor (UF). The selected units are therefore representative for the other living units in the building, except of the CA (see also chapter 3.2.1 for the detailed building parameter).

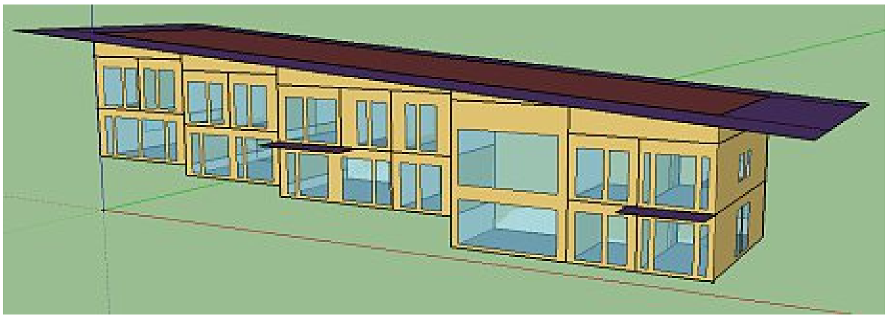

Figure 9: EP+ geometry model for the building compound

In accordance with the variables of the atrium style buildings, also parameters affecting the solar gains of the multi-storey building compound are selected. To reduce the indoor temperatures for the different thermal zones, dimensions of external shading devices are investigated (Rodrigues & Landin, 2011). A strong focus is therefore on the dimension of the large, external fixed overhanging roof element on the south side of the building compound, while the transparent elements, including the dimensions of the windows, are predefined by the architectural overall design of the building and not modified in this optimisation stage. Supplementary, the effects caused by the balconies are investigated (see Figure 9).

The variables for the parametric optimisation of the selected living units Top 2, Top 4 and Top 6 and combinations for the entire building are displayed in the following Table 3. While a detailed step of 0.1 m is used for the depth of the roof and the balconies, fixed values for the length of the balconies are used depending on the room arrangement of the living units and the location of the walls.

Table 3: Optimisation variables for the building compound

Variable	**Top 2**	**Top 4**	**Top 6**	**Combination 1**	**Combination 2**
Roof-S [m]	1.5-3.0/2.0	1.5-3.0/2.0	1.5-3.0	2.0-3.0	3.0
Depth Top 1 [m]	-	-	-	2.0-3.0	1.7-3.0
Depth Top 2 [m]	1.5-3.0	-	-	2.0-3.0	1.7-3.0
Depth Top 3 [m]	1.7	1.7	1.7	2.0-3.0	1.7-3.0
Depth Top 4 [m]	1.7	1.5-3.0	1.7	2.0-3.0	1.7-3.0
Length Top 1 [m]	-	-	-	0.0, 7.0	0.0, 7.0
Length Top 2 [m]	0.0, 3.5, 6.9	-	-	6.9	6.9
Length Top 3 [m]	5.2	5.2	5.2	5.2, 10.8	5.2, 10.8
Length Top 4 [m]	4.0	4.0, 5.5, 7.0	4.0	7.0	7.0

In a first step, the selected living units are investigated separately, whereas in a second step combinations based on the prior results for the balconies are further explored, including combinations for a variation in a loggia style for which balconies are considered along the entire south wall, except for the CA (see Figure 10).

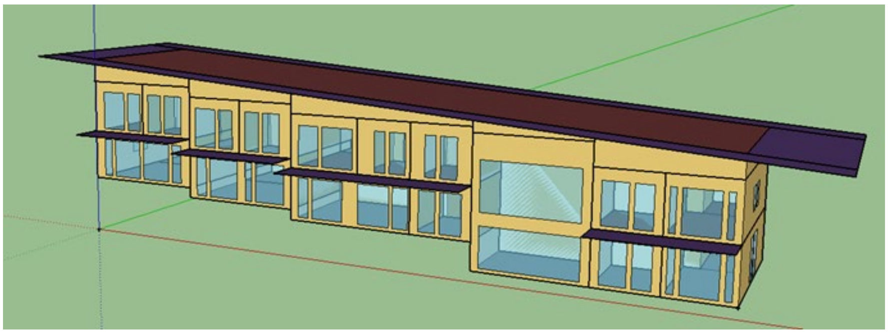

Figure 10: EP+ geometry model for the building compound loggia style

Heating and ventilation scenarios

In a second step during this optimisation phase, different heating and ventilation scenarios for the atrium buildings as well as for living units of the building compound are applied to the optimised standard HSP building model in EP+ to estimate the performance effect and the impact on the indoor climate respectively on the thermal comfort (Schuss, Taheri, Pont, & Mahdavi, 2017).

In the adapted HSP building model different temperature set points are considered, which represent more common values for the different thermal zones instead of the low standard assumption with a constant temperature of 20 °C. Accordingly also setback temperatures for night times between 11 pm and 7 am are considered. The set points for the different thermal zones are shown in Table 4.

Table 4: Adapted temperature set points

Temperatures	Bed1	Bed2	Bed3	SR	EH	HW	LK	WC	Bath	TR	CA
Set point [°C]	18	20	20	5	22	22	22	22	24	5	18
Setback [°C]	18	18	18	5	16	16	16	16	16	5	18

Furthermore, for the standard HSP model natural ventilation is considered for the summer period from 1st of May until 30th of September in order to investigate the overheating reduction possibilities for periods with indoor temperatures above 20 °C+1K. The low free cooling (FC) building model contains a rush airing (ACR=3 h^{-1}) in morning and evening times as well as ventilation with tilted windows (ACR=1 h^{-1}) during attendance times of the occupants at day and at night, while the high FC model includes also a higher night time ventilation (ACR=3 h^{-1}). It is assumed that natural ventilation is operated by the occupants. To avoid an overcooling of the building during the night, a minimum indoor activation temperature of 19 °C is set for the high FC model, defined from the setback temperature for sleeping environments of the adapted HSP building model plus 1 K.

2.3.3 Final building design stage

Proceeding from the detailed planning permit phase the building is further adapted for the final building design (FBD) in collaboration with the building companies for a cost efficient construction of these prototypes buildings.

The buildings in this phase are therefore rather optimised the other way around. Instead of improving the buildings in energy-efficiency and ecological terms, suggested cost-efficiency measures and their effects on the performance of the buildings are rather verified to maintain the minimum required target values for the heating demands according to the Austrian EPC.

The cost-efficiency measures cover besides alternative products and less expensive components, a further unification of the building elements and simplification for the manufacturing process, and even some adaptions of the architectural design. The FBD and scenarios are then compared and evaluated regarding the prior building models.

2.4 Prevention of summerly overheating

Apart from the heating demand of the buildings, the indoor environment in view of the indoor temperatures are specifically examined to avoid overheating risk and to increase the thermal comfort for the occupants. Furthermore, the potential for preventing summertime overheating is explored according to the requirements of the Austrian standards for the suggested building models. This includes an evaluation of the simplified calculation method results, the computed operative temperature during the course of the day as well as a comparison of the outcomes with the findings of the parametric simulations.

In the software GEQ for the mandatory Austrian EPC, the calculation methods in accordance with the Austrian standard ÖNORM B 8110-3 (release 2012-03-15) (Austrian Standards, ÖNORM B 8110-3 - Thermal protection in building construction - Part 3: Prevention of summerly Overheating, 2012) to avoid the overheating risk are included. The requirements of this standard for an overheating prevention in summertime have to be fulfilled according to the prior released OIB Guideline 6, OIB-330.6-094/11 (Austrian Institue of Construction Engineering, 2011). The examination of the suitability of the residential buildings can be done either by calculation of the operative temperature over the day or via to the simplified verification method. For the application of both methods the following essential conditions must be met. First, the average daily temperature of the outdoor environment needs to be not above 23 °C and second, the windows of the investigated area need to be operable for night-time ventilation.

The first method uses the operative temperature as assessment parameter, defined by the arithmetic mean value of the indoor air temperature and the average surface temperature dependent on the outdoor temperature for a repeating period of 24 h. The date used for this calculation is the 15th of July. In case the operative indoor temperature is not exceeding 27 °C the risk of overheating is considered to be avoided. In addition, for sleeping environments the minimum value of the daily operative temperature needs to be within 25 °C for times between 10 pm and 6 am. The second method, the simplified calculation method, sets the heat storage capacity of the building elements and the minimum required ventilation rate for each room in relation to the exposure surface. The suitability of the room for summertime is approved, if the heat storage capacity of the exposure surface is above the required threshold-value of the standard.

In the updated OIB Guideline 6, OIB-330.6-009/15 (Austrian Institute of Construction Engineering, OIB Guideline 6 - Energy saving and heat insulation, OIB-330.6-009/15, 2015), it is even stated that the simplified calculation method is sufficient for residential buildings in Austria and as a consequence, applied to the majority of buildings to approve the prevention of overheating in summertime. Nonetheless, an absolute planning certainty is not given for this simplified calculation approach (Nackler, 2017). The latest version of the OIB Guideline 6, OIB-330.6-026/19) (Austrian Institute of Construction Engineering, OIB Guideline 6 - Energy saving and heat insulation, OIB-330.6-026/19, 2019), therefore quotes in contrary, without any direct reference to the ÖNORM B 8110-3 standard, that overheating in summertime for residential building is avoided, if the operative temperature in the examined spaces is not exceeding the location depending daily mean value of the standard outside temperature (TNAT,13) for a periodically repeating outdoor climate by 1/3*TNAT,13+21.8 °C. While the latest version of the Austrian standard ÖNORM B 8110-3, release 2018-09-01 (Austrian Standards, ÖNORM B 8110-3 - Thermal protection in building construction - Part 3: Determination of the operating temperature in summer (Prevention of overheating), 2018), includes only the simulation method for the calculation of the operative temperature over the day for approval of the suitability regarding prevention of overheating in summertime.

The focus is therefore on the simulation of the operative temperature and on the comparison with the results of EP+ and not on the simplified method due to the adaptions in the recently released guidelines.

2.5 Ecological assessment

The ecological assessment of the prototype buildings in this study is conducted due to ecological indicators of the final building designs of each planning phase. A more detailed and encompassing evaluation regarding the entire building design like the ÖGNB of the Austrian Sustainable Building Council is not applicable for the design stage, since many criteria can be complied by a measurement method in the post-construction stage only.

The focus is therefore on the three common ecological indicators in specific the primary energy input, the global warming potential (GWP) and the acidification potential (AP) for the balancing boundary BG1 according to the OI3 guideline (IBO, 2018). The BG1 boundary includes all materials of the thermal building envelope as well as interior ceilings.

Based on the values stated in the baubook (Baubook, 2018) for the PEI, the GWP and the AP per kg for the individual building materials, also the ecological indicators for 1 m² of the construction, the entire surfaces as well as the total sum of the buildings are calculated and evaluated for the final building concepts of the three major design stages.

3 RESULTS

In this chapter the results of the three stages – early design stage, the detailed planning permit stage and the final building design stage optimisation – are presented including an analysis of the different heating and ventilation scenarios as well as an assessment of the overheating risk. Each stage begins with the description of the building parameters for both building types as starting point for the optimisation conducted. Furthermore, the most important aspects of the building project workflow are specified including a summary of an ecological evaluation.

3.1 Early design stage optimisation

3.1.1 Building parameters early design stage

Atrium buildings

In the early design stage there is in general not enough information available for performing a detailed whole building simulation with EP+. Nonetheless, simplified EP+ models, which are getting more precise during the process, are used in this stage for a first rapid design optimisation. The starting point for the optimisation process is the EPC of the preliminary design. Since the final concept for the housing technology is not selected at this early design stage, an envisaged concept is used for all EPC calculations during this phase for a comparable evaluation of the results. This concept includes solar collectors in combination with district heating from cogeneration, an efficient heating system with a heat recovery of 90 % and a floor heating system for a higher comfort of the occupants. The building parameters of the envisaged concept used for Austrian EPC are therefore not identical with all parameters of the EP+ models in this early design stage.

The single family atrium style houses (see Figure 11) have a gross floor area (GFA) of 148 m² in the preliminary design containing nine thermal zones, namely three bedrooms (Bed1, Bed2, Bed3), a storage room (SR), an entrance hall (EH), a living-kitchen area (LK), a cloakroom (WC), a bathroom (Bath) and a room for technical installations (TR).

Figure 11: Floor plan of the atrium-style building based on the preliminary design (Arch. Scheicher)

Due to the use of big straw bales for the atrium houses, the building elements show outstanding thermal properties with U-values of 0.060 W/m²K for the exterior wall, 0.068 W/m²K for the baseplate and 0.064 W/m²K for the roof construction. The building elements are listed in detail in the appendix: Atrium building elements early design stage. The buildings are supplemented with ecological solid wood frames and triple glazing components for the windows selected from the Austrian Baubook database (Baubook, 2018) using high performance average benchmark values.

Building compound

The starting point for the optimisation process of the building compound is the EPC of the preliminary design with the same envisaged concept for the housing technology like for the atrium-style buildings. Likewise for the atrium-style buildings also simplified EP+ models are used for the building compound in this early design stage.

The building compound has 6 living units and a CA with a total of 46 different thermal zones and a GFA of 788 m² in the preliminary design (see Figure 12 and Figure 13). Depending on the type and area of the building, these are namely bedrooms, SRs, EHs, hallways (HW), LKs, WCs, bathrooms, TRs and a CA.

Figure 12: Early stage design floor plan GF (Arch. Scheicher)

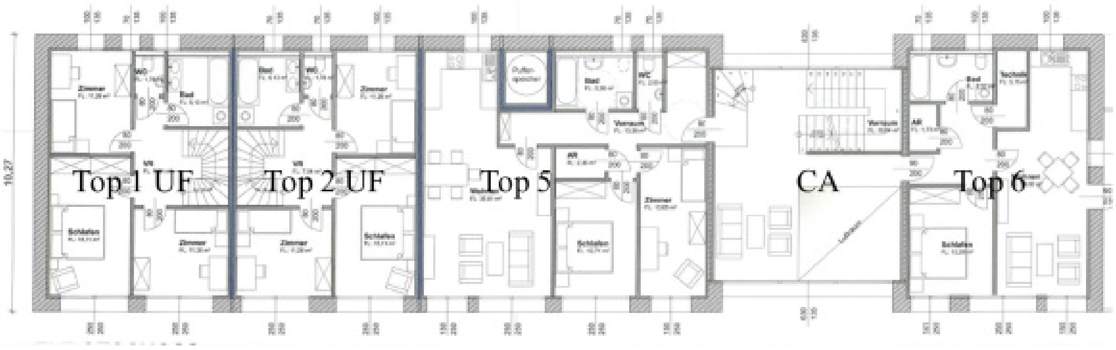

Figure 13: Early stage design floor plan UF (Arch. Scheicher)

In contrary to the single family house, it is foreseen that the building compound will be realised in a non-load-bearing straw bale construction style instead of the load-bearing big bales. The building elements show u-values of 0.13 W/m²K for the exterior wall, 0.13 W/m²K for the baseplate and 0.09 W/m²K for the roof construction, which are likewise the atrium-style buildings combined with ecological solid wood frames and triple glazing components for the windows The constructions are listed in detail in the appendix: Building compound elements early design stage.

3.1.2 Atrium buildings early design stage

The described methods (see chapter 2.3.1) for the optimisation of the building in the early design stage can be applied in one linear approach, but also in multiple attempts, depending on the specific design or e.g. in case of an alternative or varying building geometry or boundary conditions. Three approaches were carried out in this early design stage, because of a modified building design and geometry.

<u>Approach one</u>

The results for the starting point in this phase, the preliminary design with an orientation to the north and a surface-area to volume ratio (A/V) of 0.82, show a value of 20.1 kWh/(m²a) for the reference climate heating demand (HWB_RK) according to the Austrian EPC (see Table 5, preliminary design).

Window-to-wall ratio and orientation

A first and rapid analysis method of the general preliminary design is the WWR, which can also be combined with a slight rotation of the building according to different orientations of the houses using the parallel simulation method.

For the EP+ simulation the materials and constructions of the opaque building elements were used according to the EPC of the preliminary draft, while for the fenestration surfaces a simplified triple glazing construction from the EP+ database without frame was applied. Beyond that, typical objects for occupancy, people activity and infiltration were used in the model for the defined thermal zones if appropriate including an HVAC system for all zones with a heating temperature set point of 20 °C.

This first analysis shows that the comparatively large window surfaces of the preliminary draft result in the lowest heating energy demand, as does the maximum applied rotation of 20° starting from north orientation.

Window size optimisation

In a next step, EP+ in combination with GenOpt is used for optimising the sizes of the south and west oriented windows in the sleeping and living rooms. The goal is a minimum heating demand for the selected zones with a constant HSP of 20 °C and a comparatively high constant cooling set point of 40 °C for all zones, since there will probably be no active cooling device in the building.

The result of the optimisation suggests an increase of the transparent surfaces in the thermal zones situated along the building envelope. The windows in the two thermal zones situated in the centre of the building are surrounded by conditioned zones and should therefore be slightly reduced. This results in a total reduction of the transparent surfaces by 1.39 m^2.

The HWB_RK of the EPC is slightly increased to 20.3 kWh/(m^{2}a) after the optimisation (see Table 5, final phase 1), in general because the EPC software only takes the whole building envelope with the general orientation of the transparent surfaces into account, independent of the different thermal zones.

Approach two

In a next step the general floor plan of the atrium buildings was changed because of modified building product dimensions and to be able to use the brick construction method for the load-bearing straw bale walls to achieve a higher stability. A more compact energy-efficient variation was selected with a slightly bigger GFA and an A/V of 0.8 due to a modified distribution of the rooms. As a side effect also the sizes and locations of the windows were slightly changed. The HWB_RK for the initial design of phase 2 was reduced to 18.6 kWh/(m²a) (see Table 5, initial phase 2).

As the development of the building design progresses, further elements are added which made a more detailed EP+ simulation possible, such as lights and other internal gains as well as more appropriate window constructions including wood frames by selecting materials from the international glass data base (IGDB) by usage of the window creator program window 7.4. for application of benchmark values of high performance window materials (Ug=0.6 W/m²K; Uf=0.9 W/m²K; g-value=0.4).

Window size optimisation and orientation

The sizes of the fenestrian surfaces were improved as in the first approach. In the next step the parametric modelling function of EP+ was used for optimising the orientation of the current building model. The simulation was performed with a clockwise rotation step of 2.5° starting from the north axis until 90°. The lowest heating demand for this model was simulated at a rotation of 75°.

Through a further extension of the south oriented transparent building elements the solar gains can be increased and as a result the heating demand for the building according to the Austrian EPC can be further reduced. But it has to be noted that the cooling demand is not considered for residential buildings in the mandatory EPC and that there are almost no shading devices in the current model so far. This results in a high risk of overheating of the building during hot periods in summer. Accordingly, the EP+ model is simulated with a theoretical cooling set point of 30 °C together with an optimisation of the window sizes and an optimisation of the window overhang for a more appropriate shading especially for the south oriented windows.

The optimisation is also reflected in the calculation result of the Austrian EPC with an HWB_RK of 16.8 kWh/(m²a) (see Table 5, interim phase 2).

Shading device optimisation

As a consequence of the optimisation results, the design of the roof was modified. The roof overhang for the southeast and southwest oriented windows facing the courtyard is extended to prevent overheating (see Figure 14).

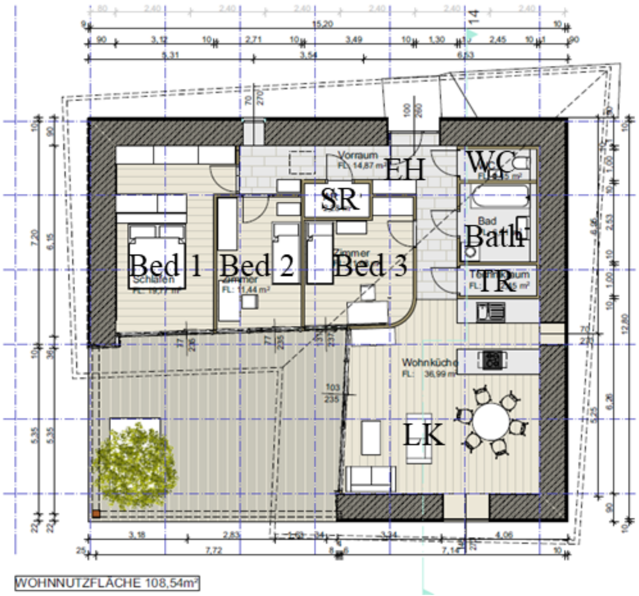

Figure 14: Optimised temporary floor plan (Arch. Scheicher)

In a further step of improving the building another shading element is necessary in addition to the overhang, for example either natural shading by the surrounding, which cannot be guaranteed at the moment, or a mechanical shading device like external shades.

GenOpt was therefore also used to define the operation set point of external shades to reduce the heating load. Since the average radiation capacity for the location is 134 W/m² the simulation was executed for a range between 125 and 175 W/m².

The optimisation of the operation for the set point of the shades in combination with the overhanging roof shows that on the one hand the depths of the roof shading should be reduced in order to increase the solar gains for the south east and south west oriented windows, while on the other hand the operation set point for the shades should be raised in the upper range to prevent overheating only during hot periods. A further reduction of the HWB_RK to 15.6 kWh/(m²a) was possible through this combined optimisation approach (see Table 5, final phase 2).

Approach three

In a final design approach, the atrium houses are relocated and connected in order to decrease the exterior wall surface for a further reduction of the heating demand (see Figure 15). As a consequence, the buildings are not anymore identical and have deviating A/V values (see also Table 5). Furthermore, the eastern building still has a window facing north east, while the western building has a comparable window facing south west.

Window size and shading device optimisation

The combined optimisation for the window sizes, the depth of the roof overhang and the operation of the external shades, described in the second approach, is repeated in the third optimisation approach for each thermal zone of the two buildings. The optimisation results show similar but slightly deviating values, which are then modified in order to unify and simplify the construction as well as the operation of the buildings.

Figure 15: Connected buildings of phase 3: Left: site plan; right: floor plan (Arch. Scheicher)

In total the heating energy demand for the EPC was decreased from 20.1 kWh/(m²a) to 14.2 (see Table 5, final phase 3 east) and 13.9 kWh/(m²a) during this simulation-supported early stage design phase (see Table 5, final phase 3 west).

Table 5: Early stage optimisation results for the atrium-style buildings

Model	**Orientation**	**GFA [m²]**	**A/V [1/m]**	**Lc [m]**	**HWB rk of envisaged concept [kWh/(m²a)]**	**EP+ heating and cooling intensity of simplified model [kWh/(m²a)]**
Preliminary design	N	148	0.82	1.22	20.1	45.22
Final phase 1	N	148	0.82	1.22	20.3	45.19
Initial phase 2	N	152	0.8	1.25	18.6	41.97
Interim phase 2	ONO	152	0.8	1.25	16.8	38.66
Final phase 2	ONO	152	0.8	1.25	15.6	35.31
Final phase 3 east	ONO	152	0.76	1.32	14.2	34.75
Final phase 3 west	ONO	152	0.75	1.33	13.9	34.22

3.1.3 Building compound early design stage

The described optimisation methods in chapter 2.3.1 are also applied for the design of the building compound in the early design stage. On the contrary to the atrium-style buildings, there is no change of the building geometry or boundary conditions of the building compound in this design phase. The methods are therefore applied in a single linear approach.

The result of the preliminary design is the starting point for the optimisation of the building compound in this approach with an orientation to the north and an A/V of 0.57.

The Austrian EPC is already showing a comparable low value of 9.8 kWh/(m²a) for the HWB_RK with the prior described constructions and housing technology (see Table 6).

Window-to-wall ratio orientation

For this first and rapid analysis method the same general parameters like for the final atrium-style buildings of this stage have been used for the EP+ building model. Simplified triple glazing construction from the EP+ database without frame for the fenestrian surfaces have been selected together with typical objects for occupancy, people activity and infiltration. In addition, the HVAC system has been improved with a heating temperature set point of 20 °C for all thermal zones as well as an increased cooling set point.

With this rapid analysis method the general preliminary design suggested by the Architect is confirmed for the envisaged orientation. Despite this optimum location because of the building site´s shape, the building model shows for the orientation of 0° to the north the lowest heating and cooling intensities.

Shading device optimisation

The window sizes of the building compound as well as the roof overhang are in contrary to the atrium-style buildings predefined by the architectural design and not investigated in this stage.

GenOpt was therefore only used to define the operation set point of additional applied external shades to reduce the heating load. The simulation was executed for a range between 125 and 175 W/m². Regarding the heating intensity there is a minor increase of 0.01 kWh/m² due to the use of external shades, but for the overall heating intensity, the results suggest a lower value to decrease the cooling energy (see Table 6). Since this parameter is not considered for Austrian EPC, there is no effect on the calculated heating demand with GEQ.

Table 6: Early stage optimisation results for the building compound

Model	Orientation	GFA [m²]	A/V [1/m]	Lc [m]	HWB rk of envisaged concept [kWh/(m²a)]	EP+ heating and cooling intensity of simplifies model [kWh/(m²a)]
Preliminary design	N	788	0.57	1.76	9.8	10.29
Final design	N	788	0.57	1.76	9.8	7.63

3.1.4 Workflow early design stage

The starting point for the early design stage is the preliminary design of the buildings (see also Figure 5) and in specific the plans sketched by the architect based on the conceptual project idea of the project leader.

The design optimisation of the prototype buildings in this stage is carried out by the project management team only including the project leader, the architect and the engineering office. Other partners of the projects overall cooperation network (see Figure 4) have not been involved in the developing processes of the final planning design of this stage. The system boundaries for the workflow during the early design stage are highlighted in Figure 16.

Since the development of the building concept and optimisation of the design is limited to the project management, also the information flow in this stage is overseeable. The areas of expertise are clear as well as the tasks assigned to the respective involved partner. The communication is taking place on demand via email, phone conference or meetings. No relevant obstacle during the early design stage can be reported. All building design optimisation suggestions have been reviewed and, depending on the compatibility with the overall project objectives, accepted by the project leader.

As stated in chapters 3.1.2 and 3.1.3, the optimisation was conducted in a circular approach for the atrium-style buildings because of changed building geometry and boundary conditions and in a single linear approach for the building compound, to be finalised in the suggested building designs of this stage.

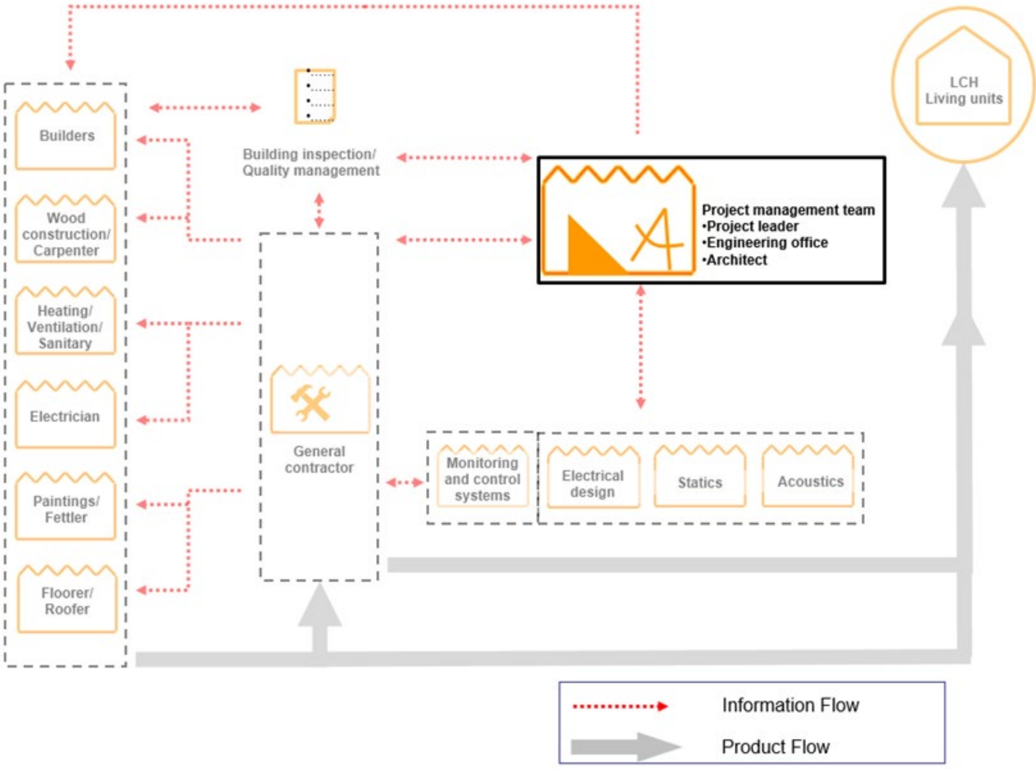

Figure 16: Workflow of the early design stage

3.2 Detailed planning permit stage

3.2.1 Building parameters detailed planning permit stage

<u>Atrium buildings</u>

Proceeding from the design planning and the results of the early stage optimisation (see section 3.1.2), the single-family houses will be built in a load-bearing straw bale construction style using big bales with a clay layer on the inside and a lime layer on the outside.

Thus, in contrary to the results of the final building models of the 3rd approach in the early design stage, the shape of the atrium-style buildings and also the arrangements of the rooms within the building are mirrored. Due of this action, the buildings can be positioned with its eastern wall along the border of the construction site, while maintaining the optimised orientation of the transparent surfaces of the living area and the bed rooms to the south (see Figure 17).

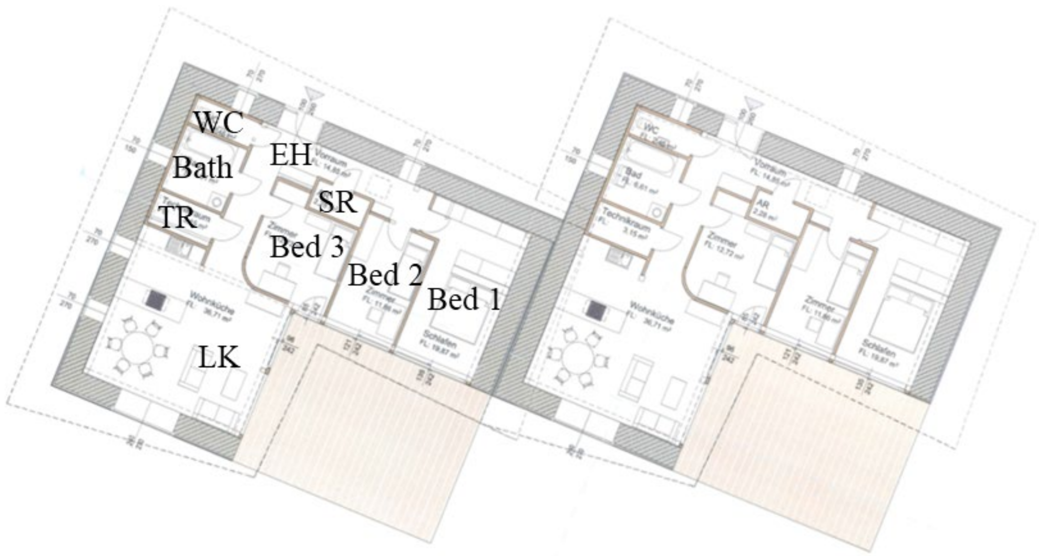

Figure 17: Floor plan of the atrium-style buildings based on the planning design (Arch. Scheicher)

Like in the prior stage the usable floor space will be 107 m² for each building containing nine thermal zones. These are three bedrooms (Bed1, Bed2, Bed3), a SR, an EH, a LK, a WC, a bathroom and a TR.

The buildings are connected for reducing the exterior surface of the building envelope, thus need to be vertically shifted in consequence of the building area's slope (see Figure 18).

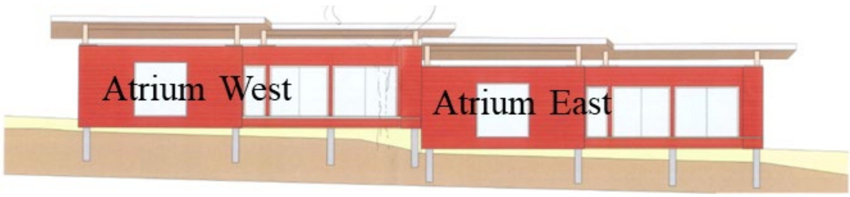

Figure 18: South view of the atrium-style buildings (Arch. Scheicher)

The highly thermally insulating building envelope (exterior wall=0.06 W/m²K; roof=0.06 W/m²K; floor=0.07 W/m²K) is combined with triple layer windows using benchmark values (Ug=0.6 W/m²K; Uf=0.9 W/m²K; g-value=0.4) and an overhanging roof to improve the performance of the building. The constructions of the building elements are listed in detail in the appendix: Atrium building elements detailed planning permit stage.

For a comparison of the results also in this stage the same concept for the housing technology is used for all calculations of the EPC. This energy concept includes, like in the early design stage for the atrium-style buildings, solar collectors in combination with district heating from cogeneration and an efficient heating system with a heat recovery of 90 %.

<u>Building compound</u>

Continuing with the optimisation of the building compound based on the results of the prior stage (see section 3.1.3), these living units will be realised in a non-load-bearing straw bale construction style. This two-storey building compound (see Figure 19 and Figure 20) consists of two living units in a town house style, a CA and 4 apartments with a total of 41 different thermal zones instead of 45 thermal zones of the early design stage. Due to the overall optimised building design, there is no demand for an additional TR within the individual apartments. Accordingly, also the layout of the rooms has changed.

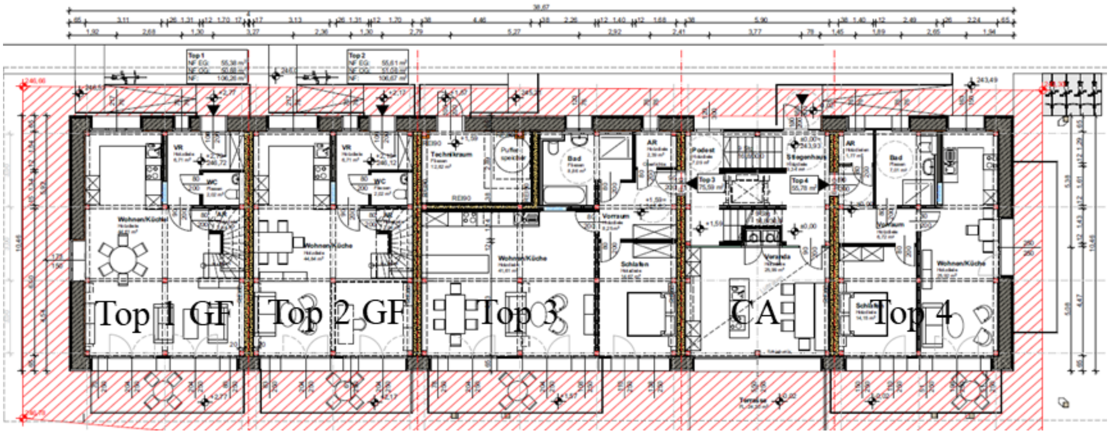

Figure 19: Floor plan GF: Top 1, Top 2, Top 3, CA, Top 4 (Arch. Scheicher)

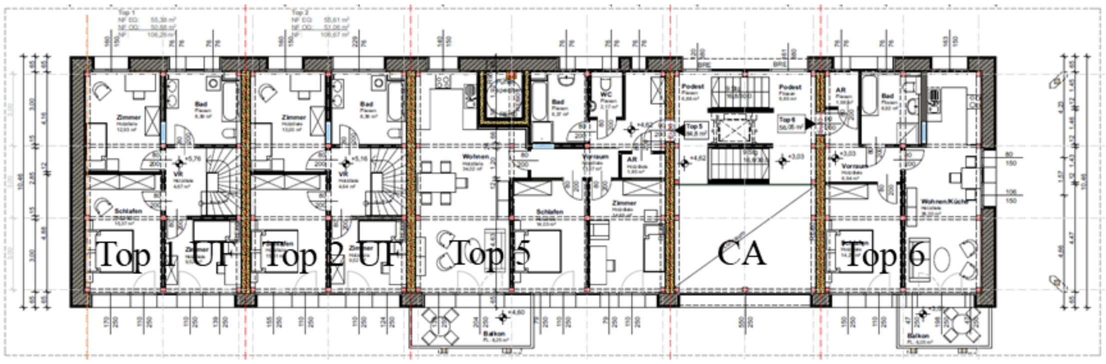

Figure 20: Floor plan UF: Top 1, Top 2, Top 5, CA, Top 6 (Arch. Scheicher)

Same as the atrium-style buildings, the single living units are vertical shifted because of the slope on the construction site (see Figure 21).

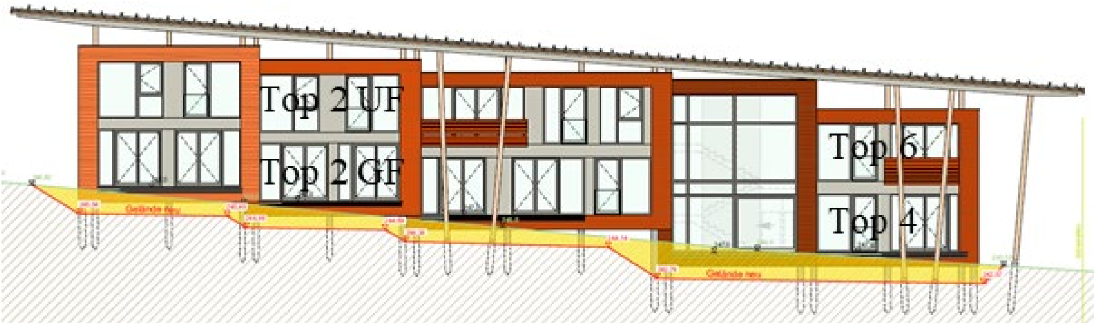

Figure 21: South view of the building compound (Arch. Scheicher)

As described in the methodology section 2.3.2, three living units are selected for a further design optimisation. These are Top 2, Top 4 and Top 6. Top 2 is a 2-storey living unit with a total of 106.67 m² on both floors and 8 thermal zones. These are an EH, a LK and a WC in the GF as well as a HW, three bedrooms (Bed1, Bed2, Bed3) and a bathroom in the UF (see Figure 22).

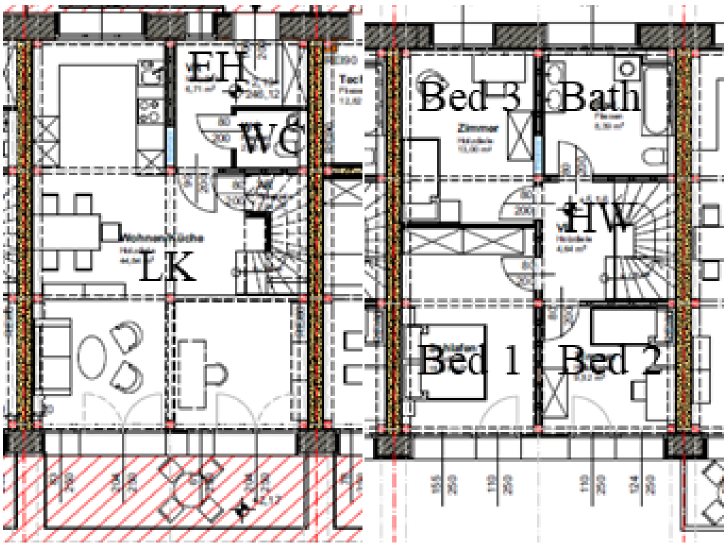

Figure 22: Left: Floor plan Top 2 GF; right: Top 2 UF (Arch. Scheicher)

The other two living units are apartments and consist of 5 thermal zones, each including an EH, a SR, a LK, a bathroom and a bedroom (Bed1). They have a net living area of 56 m². Top 4 is located in the GF, while Top 6 is located in the UF (see Figure 23).

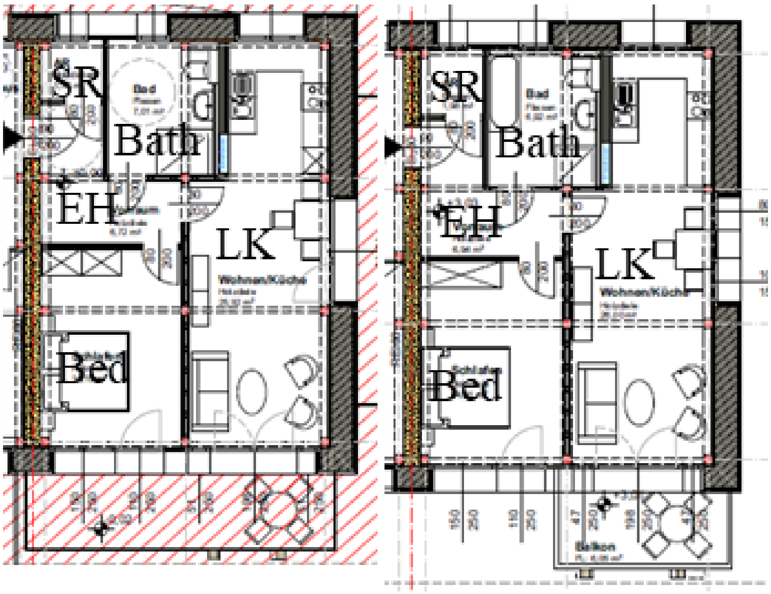

Figure 23: Left: Floor plan Top 4 GF; right: Top 6 UF (Arch. Scheicher)

The building elements of this non-load-bearing straw bale construction are bearing also high thermally insulating properties (exterior wall=0.09 W/m²K; roof =0.07 W/m²K; floor=0.09 W/m²K; partition wall=0.11 W/m²K), which are combined with the same triple layer window elements using typical benchmark values (Ug=0.6 W/m²K; Uf=0.9 W/m²K; g-value=0.4) like the atrium-style buildings. The detailed building elements are listed in the appendix: Building compound elements detailed planning permit stage.

The building will also be completed with an innovative energy system based on locally available renewable energies for further reduction of the carbon footprint. This system's concept includes first solar collectors in combination with district heating from cogeneration, second an efficient heating system with a heat recovery of 85 % and third a floor heating system for a higher comfort of the occupants like in the prior stage. This same system is used for all EPC calculations during this stage for a comparable evaluation of the results.

Parameters for EnergyPlus models

The simulation models are defined based on standard assumptions according to the calculation methods of the Austrian EPC with a standard HSP of 20 °C and a fixed ACR of 0.4 h^{-1} as already described in chapter 2.3.2. Other necessary important input parameters for the simulation of the EP+ models, which have e.g. a strong effect on the internal gains like the occupancy or the installed equipment, are defined according to the purpose of the buildings to be used for human habitation. The parameters are described in the following section.

Occupancy

According to the project goals, the intended usage of the buildings is for human habitation. Therefore, typical schedules regarding occupancy and user behaviour are applied for the different selected living units. The atrium-style buildings and Top 2 are designed as four person households, while the smaller apartments Top 4 and Top 6 are designed as two person households. It is assumed that the people living in the selected living units are employed or at school and therefore usually not at home during the day. This is assumed since professionals are covering with 4.26 of 8.79 million the largest group in Austria in 2017 (Statistik Austria, 2018). A general daily routine for occupancy starts in the morning between 7 and 8 a.m. with a sequence of activities: waking up in the bed rooms, using the bathroom, WC and the kitchen area before leaving the building. In the evening at around 6 p.m. the activities start after returning back home in the living area, and if applicable in case of the four person households, in the single bed rooms. A similar course of the day is assumed for weekends but with a varying time schedule. There is no occupancy scheduled for the storeroom, which is a functional area only and the time people spend in there is normally reduced to a minimum. Also the EH and the HW are considered as transit zones. A detailed overview for the total daily occupancy hours for each zone of the selected living units independent of the number of persons is shown in the appendix in Table 80 for weekdays and in Table 81 for weekends.

Activity level

According to the design of the buildings typical activities (U.S. Department of Energy, EnergyPlus Input Output Reference, 2017) are assumed for the occupants, varying from sleeping to housecleaning, which are in accordance with the ASHRAE standard (ASHRAE HANDBOOK, 2005). Combined values reflecting varying activities for the different thermal zones are selected depending on the purpose of each area. Appropriate activities for the main bedroom are sleeping (72 W/person) and reclining (81 W/person). For the additional or children´s bedroom activities like sleeping, sitting and writing (108 W/person) or light exercises (>315 W/person) are expected. For the combined living and kitchen area assumed activities are sitting and reading (99 W/person), cooking (171 to 206 W/person) or housecleaning (>207 W/person). In the bathroom metabolic rates for sitting, standing or relaxed walking (126 W/person) are anticipated, while for the staircase a metabolic heat generation like for a walkabout is assumed (150 W/person). An overview of the maximum combined values for the metabolic rates in each zone of the selected living units is displayed Table 82 in the appendix.

Internal gains of equipment

For other internal gains caused by different devices in the living units, a standard electric equipment is to be considered (Stephan, Béjat, Flechon, & Cook, 2018) – in accordance with the defined values of the ASHRAE standard (ASHRAE HANDBOOK, 2005), but slightly adapted in terms of an energy-efficient overall system. These are for example cooking devices in the kitchen, TV´s and or computer in the living area or in bedrooms as well as washing machines or other laundry devices and hairdryer in the bathroom. Therefore, internal gains of e.g. maximum 800 W are assumed for the living kitchen area, a maximum of 600 W for the bathroom or a maximum of 100 W for the bedroom depending on occupancy and people´s activity. The lights are not included in these numbers. A more detailed list of the internal gains caused by electric equipment is displayed in Table 83 in the appendix.

Lights

To achieve an efficient overall energy system of the building, presumably also energy-efficient equipment and lighting devices are installed in the living units. For the living units a total installed lighting power of 328 W for the atrium-style buildings, 326 W for Top 2 as well as 228 W for Top 4 and Top 6 is considered. The data is chosen according to recommended lighting levels for the different zones in residential buildings (co2online, 2018) considering the use of low-energy light bulbs or LED´s. A detailed distribution for the installed lighting power for each zone of the living is displayed in Table 84 in the appendix.

Dynamic shading

In addition to the external fixed shading devices, in specific the overhanging roof and balcony elements, a mechanical shading system is added for the south-oriented windows of the building compound and the atrium-style buildings. This shading system should help to support the prevention of an overheating of the buildings during hot summer days, but not to block the solar gains in wintertime when needed. Subsequently it is only seasonal operated during summer, being activated due to high solar radiation on the windows surface. A set point of 146 W/m² is selected, which is correlating to a light intensity of a bright and sunny day with approximately 100.000 lx (MDT technologies, 2013) considering a wave length of 550 nm. This set point value is above the annual average solar radiation of 134 W/m² for Böheimkirchen (Meteonorm, 2016). It is also in line with recommended set point values to guarantee a visual comfort as well as is in the operation range of typical manual controlled shades (Atzeri, Pernigotto, Cappelletti, Gasparella, & Tzempelikos, 2013).

Furthermore, to achieve a big effect in this peak hours during hot periods, exterior shades with a high reflection are used for the building model.

3.2.2 Optimisation results atrium buildings

Approach one

Heating demand and overheating of the buildings

With the overall goal of achieving a heating demand HWB_RK of maximum 15.0 kWh/(m²a) according to the Austrian EPC, first a parametric simulation was done in EP+ with the in chapter 3.2.1 described building models and variables as well as combinations of these. Second, the results were then compared regarding the two PIs heating demand and overheating risk of the building due to the indoor temperatures. The models are showing results between 14.1 and 16.3 kWh/(m²a) for the concurrently computed heating demand HWB_RK with the software GEQ. Variants with a HWB_RK above 15.0 kWh/(m²a) are excluded. Especially variants with additional north-facing windows are exceeding this value. As a consequence, a model with huge south-facing windows for high solar gains (see Table 7) and large overhangs to prevent overheating (see Table 8) is suggested.

Table 7: Optimisation results for window width variables

Building	**EH-NNE [m]**	**Bed1-NNE [m]**	**Bed1-EES [m]**	**LK-SSW [m]**	**LK-WWN [m]**
Atrium East	0.0	-	0.6	2.2	-
Atrium West	0.0	0.0	-	2.2	0.0

Table 8: Optimisation results for overhang depth variables

Building	**NNE [m]**	**EES-1 [m]**	**EES-2 [m]**	**SSW-1 [m]**	**SSW-2 [m]**
Atrium East	1.0-1.5	0.7	1.5	1.0	1.2
Atrium West	1.3-1.5	-	1.5	1.0	1.3

The suggested model with a computed HWB_RK of 15.0 kWh/(m²a), which is within the threshold value, is showing with values of 1851 and 1901 the smallest numbers of hours for indoor temperatures above 26 °C (see Table 9), compared to the average value of 1975 h and the maximum of 2227 h considering all simulated variants.

Table 9: Time with indoor temperatures > 26 °C for optimised standard HSP model

Building	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	LK [h]	WC [h]	Bath [h]	Zones 1-8 [h]
Atrium East	1287	1602	1318	865	715	1786	382	976	1901
Atrium West	935	1527	1265	761	628	1748	347	940	1851

Heating and ventilation scenarios

In the following section the results of the in chapter 2.3.2 specified heating and ventilation scenarios to estimate the performance effect and the impact on the indoor climate are described in detail. An overview of both atrium-style buildings is given in Table 10. This includes the calculated heating intensities by EP+ as well as the sum of hours of the indoor temperature above 26 °C for the entire year and for the summer season only.

Table 10: Scenario results for building model with heating demand HWB_RK of 15.0 kWh/(m²a)

Scenario	EnergyPlus heating intensity	Hours with temperatures > 26 °C for zones 1-8	
	[kWh/(m²a)]	All year [h]	Summer period [h]
Standard HSP Atrium East	16.63	1901	1689
Adapted HSP Atrium East	23.90	1938	1692
Low FC Atrium East	16.60	922	709
High FC Atrium East	16.73	344	133
Standard HSP Atrium West	16.65	1851	1657
Adapted HSP Atrium West	24.03	1894	1666
Low FC Atrium West	16.62	879	684
High FC Atrium West	16.63	410	215

The indoor temperatures of the Atrium East building for the standard HSP scenario with a temperature set point of 20 °C are illustrated in Figure 24 for the different thermal zones, while the ones for the adapted HSP scenario with more common temperature set point values are displayed in Figure 25.

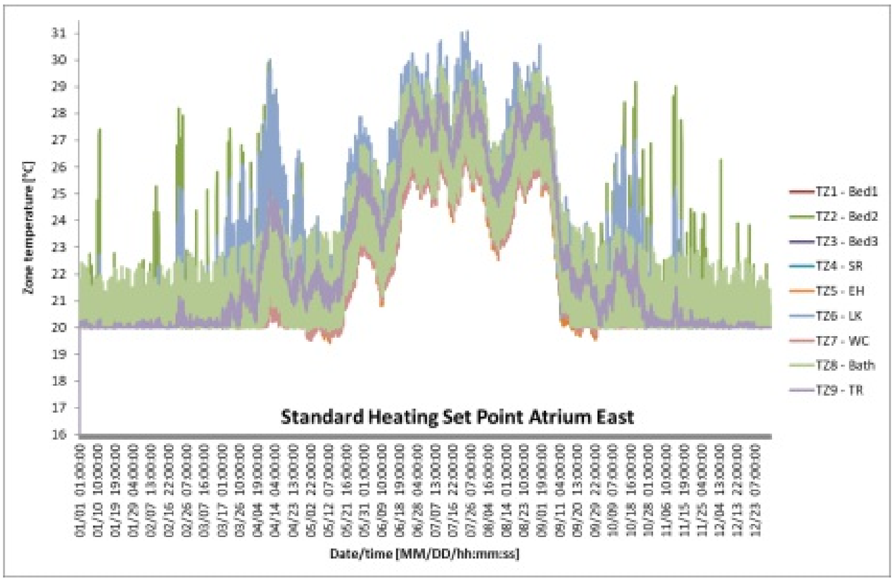

Figure 24: Indoor air temperatures for the standard HSP model of the Atrium East building

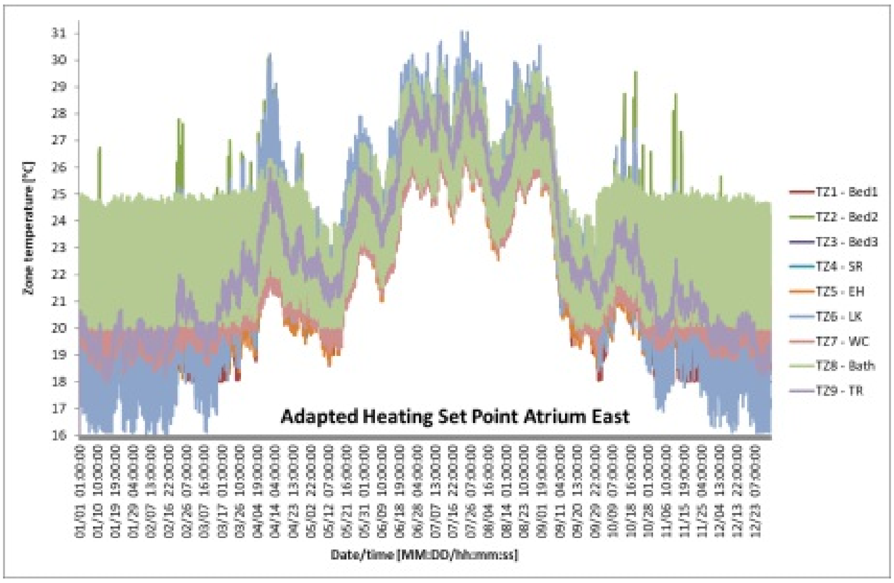

Figure 25: Indoor air temperatures for the adapted HSP model of the Atrium East building

The adapted HSP model shows wider variations depending on the selected set point values with a reduced night time temperature of 16 °C and increased daytime temperatures for selected zones. As a result, the computed heating intensities in EP+ would increase by 7.26 kWh/(m²a) for the Atrium East and by 7.38 kWh/(m²a) for the Atrium West building model. The total number of hours with indoor temperatures above 26 °C would also increase slightly. The indoor temperatures for the standard and adapted HSP models for Atrium West building are displayed in Figure 74 and Figure 75 in the appendix.

In contrast, due to the application of natural ventilation to the standard HSP model in the summer period, a significant reduction of the indoor temperatures can be achieved.

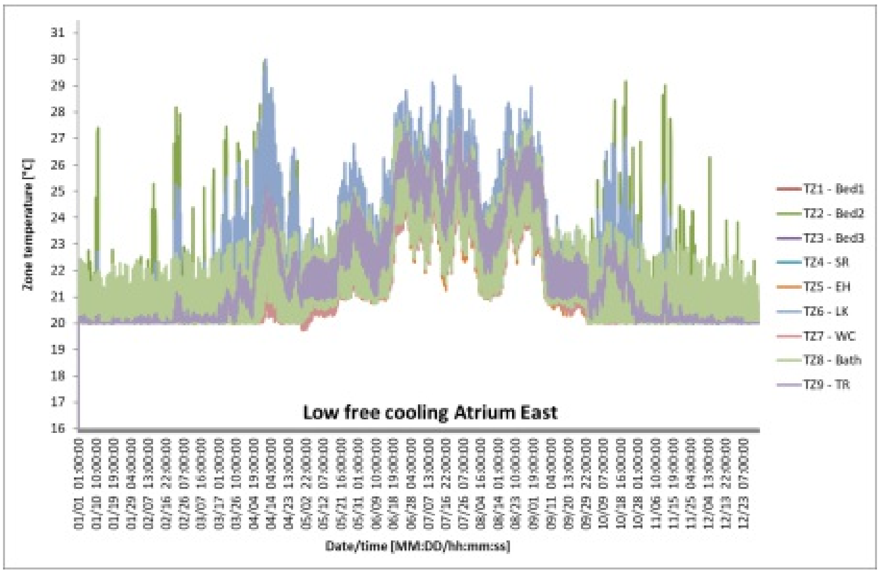

Figure 26: Indoor air temperatures for the low FC model of the Atrium East building

For the low FC model this results in a decrease of 51.5 % to 922 h of Atrium East and of 52.5 % to 879 h for Atrium West considering the timespan of the entire year, while for the summer period reductions of 58.7 % to 684 h and of 58.0 % to 709 h can be achieved (see Figure 26 and Figure 76 in the appendix).

For the high FC model even reductions by 81.9 % to 344 h for Atrium East and by 77.8 % to 410 h for Atrium West are possible for the whole timeframe, caused by the higher ACR especially during the night, whereas in the summer period decreases by 92.1 % to 133 h and by 87.9 % to 215 h are achievable (see Figure 27 and Figure 77 in the appendix).

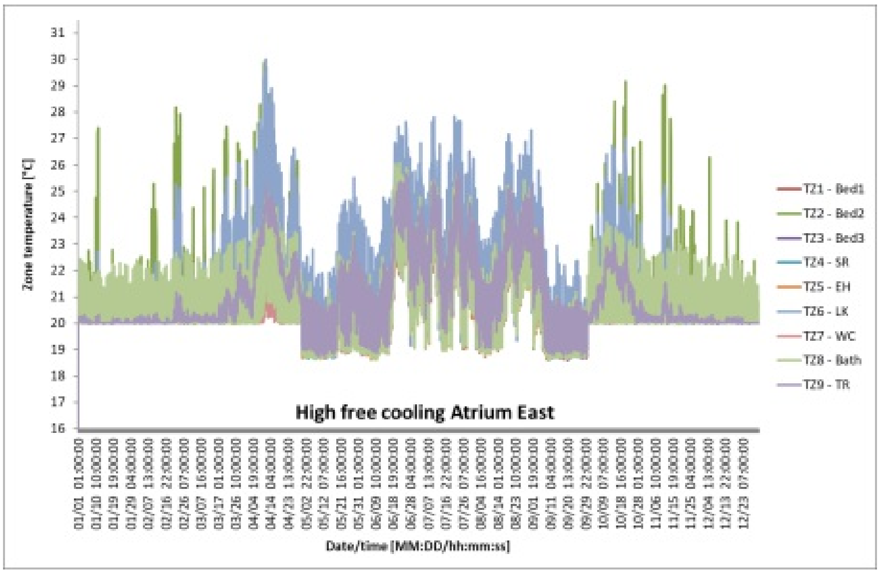

Figure 27: Indoor air temperatures for the high FC model of the Atrium East building

Approach two

Heating demand and overheating of the buildings

Due to an ongoing improvement of the overall building design, in this stage a second optimisation approach is done for the shading design of the atrium-style buildings. For these building models, the modifications were described in chapter 2.3.2. The replacement of the window elements in the northwest corner of the building by solar tubes in the roof to provide daylight for the areas of the bath, WC, EH and the kitchen have been considered, as well as the implementation of an additional window in the northeast corner to provide a panoramic view for the Atrium East building of the surrounding countryside in accordance with the suggestions for the width of windows (see also Table 7). The GFA for the atrium-style buildings remains the same, although some adaptions have been done compared to approach one in this phase including a varying room layout. In specific, the location of the bath and the WC has been interconverted in context due to an optimised layout of the sanitary equipment. Furthermore, some adaptions of the construction materials are leading to an increased performance of the building envelope (exterior wall=0.06 W/m²K; roof=0.06 W/m²K; floor=0.05 W/m²K), first due to the use of blow-in insulation made of straw (λ = 0.043 W/mK) instead of big bales (λ = 0.050 W/mK) for the roof and floor elements, because of a lower lambda-value, second material reductions of the wood elements are possible for a less resource-intense construction. Also green roofs should be provided for the atrium-style buildings.

These amendments together with the suggested parameters for the shading design of the buildings (see Table 8) are leading to decreased heating demands according to the Austrian EPC with values of 13.0 kWh/(m²a) for the HWB_RK and 14.9 kWh/(m²a) for the location climate heating demand (HWB_SK) of the Atrium East building and 13.0 kWh/(m²a) for the HWB_RK and 14.8 kWh/(m²a) for the HWB_SK of the Atrium West building. Supplementary, also the number of hours for indoor temperatures above 26 °C are reduced for the standard HSP building models of the adapted building design (see Table 11).

Table 11: Time with indoor temperatures > 26 °C for standard HSP model of approach 2

Building	**Bed1 [h]**	**Bed2 [h]**	**Bed3 [h]**	**SR [h]**	**EH [h]**	**LK [h]**	**WC [h]**	**Bath [h]**	**Zones 1-8 [h]**
Atrium East	1259	1541	1122	721	731	1694	627	648	1876
Atrium West	968	1413	1078	664	656	1631	657	637	1777

Taking these values as starting point for the second optimisation approach regarding the shading design in the detailed planning permit phase for the parametric simulation with EP+ an overall goal of maximum 15 kWh/(m²a) for the HWB_SK according to the Austrian EPC was chosen as thresh-hold value. The results suggest adaptions for the design of the roof overhang (see Table 12) to increase the thermal comfort for the occupants considering the 2 key PIs and also a unification of the roof design for the connected atrium-style buildings.

Table 12: Optimisation results for overhang depth variables of the adapted building model

Building	**NNE [m]**	**EES-1 [m]**	**EES-2 [m]**	**SSW-1 [m]**	**SSW-2 [m]**
Atrium East	1.3	0.5	1.5	1.3	1.3
Atrium West	1.3	-	1.5	1.3	1.3

The suggested building models with computed values of 13.1 kWh/(m²a) for the HWB_RK and 15.0 kWh/(m²a) for the HWB_SK of the Atrium East building and of 13.1 kWh/(m²a) for the HWB_RK and 14.9 kWh/(m²a) for the HWB_SK of the Atrium West building are showing with values of 1861 and 1761 the smallest numbers of hours for indoor temperatures above 26 °C (see Table 13) for a unified design considering all simulated variants.

Table 13: Time with indoor temperatures > 26 °C for optimised standard HSP model of approach 2

Building	**Bed1 [h]**	**Bed2 [h]**	**Bed3 [h]**	**SR [h]**	**EH [h]**	**LK [h]**	**WC [h]**	**Bath [h]**	**Zones 1-8 [h]**
Atrium East	1223	1528	1127	728	726	1678	624	648	1861
Atrium West	948	1406	1080	668	659	1602	654	633	1761

3.2.3 Optimisation results building compound

Heating demand and overheating of the buildings

In contrary to the atrium-style buildings, the building compound and therefore also the single living units have a different target value because of the differing construction style and compactness with a A/V of 0.54 compared to 0.77 1/m of the atrium-style buildings. Therefore, a value of 10 kWh/(m²a) for the heating demand HWB_RK according to the Austrian EPC is the general target. Same as for the atrium buildings, a concurrently executed parametric simulation was done with EP+ to evaluate the second key PI the overheating of the building due to the indoor temperatures for the in section 3.2.1. described building models.

The models are showing results between 7.9 and 9.7 kWh/(m²a) for the computed heating demand HWB_RK with the software GEQ. In contrary to the atrium style buildings, where models with results above the threshold-value are excluded, all computed results for the models of the building compound are within the target area. Therefore, not only one but a range of improved models suitable for the building are suggested depending on the different combination possibilities for the selected variables. Looking at an optimisation of the single living units separately of the overall design of the building compound, models with large overhangs for the roof and the balconies on the south-façade of the building are in general suggested for a decreased overheating risk.

In a first step, the effect of the depth of the overhanging roof was explored for the selected living units. In case of Top 2 and Top 4 also the lengths and depths of the balconies were investigated. The smallest numbers of hours for the indoor temperatures above 26 °C for the selected living units are shown in Table 14, while the corresponding variables are displayed in Table 15.

Table 14: Time with indoor temperatures > 26 °C for optimised standard HSP models of the living units

Living unit	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	All [h]
Top 2	1975	2439	1507	-	777	1083	1347	1019	1261	2491
Top 2-roof	1951	2346	1540	-	723	1169	1504	964	1303	2466
Top 4	2038	-	-	1423	1499	-	2139	-	1703	2318
Top 4-roof	2368	-	-	1378	1447	-	2240	-	1661	2639
Top 6-roof	2200	-	-	1297	1397	-	2022	-	1585	2404

In general, the extension of the overhanging roof as well as an enlargement of the balconies result in a reduction of the indoor temperatures. As a consequence of these increased variables, also the heating demand of the building is increased accordingly due to less solar gains and because of the extended shading devices. While the extension of the roof has a higher effect on the zones of the UF, the enlargement of balconies is mainly influencing the south-oriented zones in the GF. The suggested models are showing values of 2491 and 2466 h for Top 2, 2318 and 2639 h for Top 4, and 2404 h for Top 6, compared to the average values of 2501, 2544 and 2497 h as well as to the maximum values of 2555, 2668 and 2571 h considering all simulated variants.

In a next step the variables are combined for a further building optimisation. Based on the previous results, combinations in which the depths of the roof and the balconies are extended in parallel including the appended balcony element for Top 2 are investigated in detail. In addition, also variations with a maximum roof overhang of 3 m and an extension of the balcony depth with a step of 0.1 m are explored.

Table 15: Optimisation results for the building compound variables

Variable	Top 2	Top 4	Top 6	Combined	Loggia style
Roof-S [m]	3.0	3.0	3.0	3.0	3.0
Depth Top 1 [m]	-	-	-	-	3.0
Depth Top 2 [m]	3.0	-	-	3.0	3.0
Depth Top 3 [m]	1.7	1.7	1.7	3.0	3.0
Depth Top 4 [m]	1.7	3.0	1.7	3.0	3.0
Length Top 1 [m]	-	-	-	-	7.0
Length Top 2 [m]	6.9	-	-	6.9	6.9
Length Top 3 [m]	5.2	5.2	5.2	5.2	10.8
Length Top 4 [m]	4.0	7.0	4.0	7.0	7.0

The suggested model with a computed HWB_RK of 9.1 kWh/(m²a), which is within the threshold value, is with 2356 h for Top 2, 2303 h for Top 4 and 2360 h for Top 6 showing further reduced numbers of hours for indoor temperatures above 26 °C (see Table 16). Overarching, this results in 2586 h for the three living units altogether.

Table 16: Time with indoor temperatures > 26 °C for the optimised standard HSP model of the compound

Living unit	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	All Zones [h]
Top 2	1953	2318	1569	-	827	1222	1400	1074	1320	2356
Top 4	2027	-	-	1416	1488	-	2137	-	1704	2303
Top 6	2165	-	-	1313	1412	-	2016	-	1602	2360

In addition, the combinations are also applied for the building in a loggia style for which the balconies are considered along the entire south façade of the building compound. In this case the numbers of hours for the indoor temperatures above 26 °C for the suggested building model are 2356 h for Top 2, 2294 h for Top 4 and 2355 h for Top 6 (see Table 17).

Comparing the loggia style model with the optimised basic variant of the building compound, it shows a slightly lower value of 2579 h for all three living units together, but a higher computed HWB_RK of 9.7 kWh/(m²a), because of the overall enlargement of shading devices considering the entire building.

Table 17: Time with indoor temperatures > 26 °C for the optimised standard HSP model loggia style

Living unit	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	All Zones [h]
Top 2	1967	2318	1575	-	836	1228	1409	1085	1323	2356
Top 4	2022	-	-	1412	1485	-	2132	-	1705	2294
Top 6	2157	-	-	1302	1404	-	2011	-	1595	2355

Heating and ventilation scenarios

Continuing from the suggested building model for the compound (see Table 16), the results for the specified heating and ventilation scenarios are described in the following section. Table 18 is summarising the impact on the indoor climate of the selected living units due to the sum of hours of the indoor temperatures above 26 °C. Table 19 is providing an overview for the combined living units within the building compound including the calculated heating intensities by EP+.

Table 18: Scenario results of the suggested building model for the optimised living units of the compound

Hours with temperatures > 26 °C for all zones per living unit	Standard HSP [h]	Adapted HSP [h]	Low FC [h]	High FC [h]
Top 2 All year	2356	2461	1366	608
Top 2 summer period	2043	2056	1053	295
Top 4 All year	2303	2337	1459	573
Top 4 summer period	2163	2165	1319	435
Top 6 All year	2360	2415	1390	589
Top 6 summer period	2069	2081	1099	299

The results are showing in general similar tendencies for the selected living units Top 2, 4 and 6 for the different scenarios.

Same like for the Atrium buildings the adapted HSP scenarios are showing wider temperature variations than the standard HSP scenarios, because of the different temperature set point values. The standard HSP scenario for Top 2 with a constant heating temperature set point of 20 °C is displayed in Figure 28, while the ones for Top 4 and Top 6 are shown in Figure 78 and Figure 79 in the appendix.

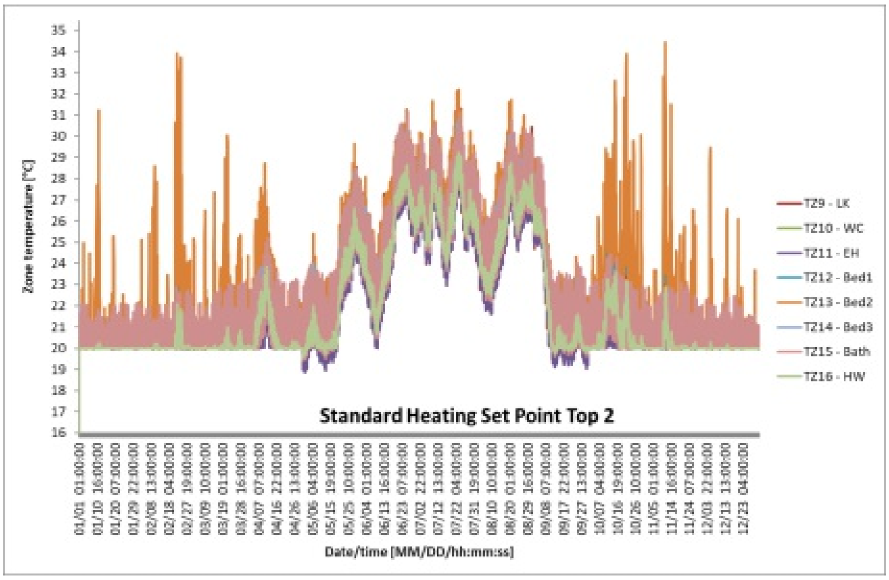

Figure 28: Indoor air temperatures for the standard HSP model of Top 2

Especially during the summer season with a warmer outdoor environment and higher solar radiation also the number of hours of the indoor temperatures above 26 °C are increasing. The occasionally occurring high values during hot periods of single days in spring and autumn, especially for the south oriented rooms in the UF, are arising due to the mechanical shading system, which is only seasonal operated during summer in this building model.

The adapted HSP scenarios, which are representing more common temperature set points, are illustrated in Figure 29 in case of Top 2 as well in Figure 80 for Top 4 and in Figure 81 for Top 6. These are reflecting the increased daytime temperatures for selected zones like the bathroom, as well as the reduced night time temperatures.

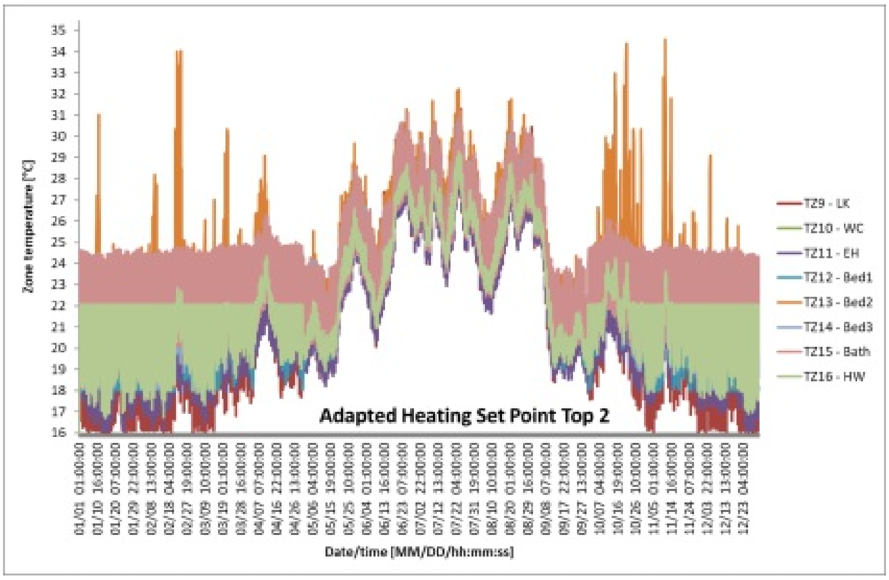

Figure 29: Indoor air temperatures for the adapted HSP model of Top 2

Likewise the atrium style buildings, also the living units of the building compound are showing a significant reduction of the indoor temperatures above 26 °C for the low FC model due to the application of natural ventilation to the standard HSP model (see Figure 30 for Top2, Figure 82 for Top 4 and Figure 83 for Top 6).

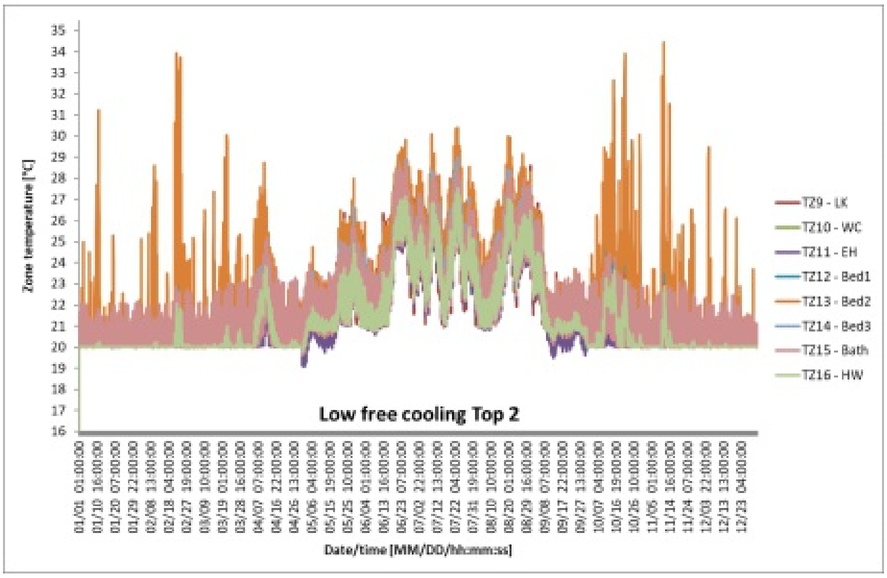

Figure 30: Indoor air temperatures for the low FC model of Top 2

The integrated natural ventilation results in case of the low FC building model to a fall-off by 42.0 % to 1366 h for Top 2, by 36.6 % to 1459 h for Top 4 and by 41.1 % to 1390 h for Top 6 for the period of a whole year, while for the summer time reduction of 48.5 % to 1053 h, 39.0 % to 1319 h and 46.9 % to 1099 h can be achieved for Top 2, 4, and 6 (see Table 18).

The results for the high FC model are illustrating that increased natural ventilation with a higher ACR can significantly further improve the thermal comfort for the indoor environment during the hot summer period (see Figure 31, Figure 84 and Figure 85).

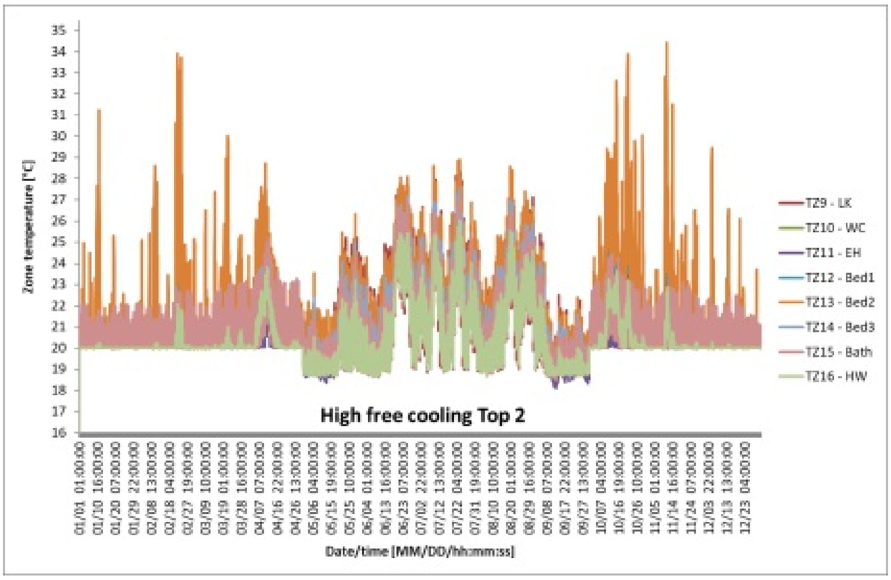

Figure 31: Indoor air temperatures for the high FC model of Top 2

Due to the increased ACR during night times, reductions by 74.2 % to 608 h for Top 2, by 75.1 % to 573 h for Top 4 and by 75.0 % to 589 h for Top 6 can be achieved compared to the standard HSP scenario considering the period of a whole year. Comparing the total number of hours above 26 °C for the summer period decreases by 85.6 % to 215 h for Top 2, by 79.9 % to 435 h for Top 4 and by 85.6 % to 299 h are possible (see also Table 18).

Examining the calculated heating intensities in EP+ of the entire building of the different heating and ventilation scenarios, the adapted HSP scenario shows with 21.13 kWh/(m²a) an increase of 5.06 kWh/(m²a) in comparison to the standard HSP scenario (see Table 19).

Comparing the total number of indoor temperatures above 26 °C for the three selected zones together, the adapted HSP is also showing a slight increase from 2586 h to 2634 h for the entire year and from 2170 h to 2172 h for the summer period only. For the individual living units and the combined selected living units, the results are showing a significant reduction of the indoor temperatures above 26 °C due to the application of natural ventilation in the standard HSP model. A decrease of 32.8 % to 1739 h and of 39.0 % to 1323 h can be achieved for the low FC model and of 67.1 % to 851 h and of 79.1 % to 436 h for the high FC model in the periods of an entire year and for the summer months (see Table 19).

Table 19: Scenario results for the suggested building model of the compound

Scenario	EnergyPlus heating intensity compound [kWh/(m²a)]	Hours with temperatures > 26 °C for all zones of Top 2, 4 and 6	
		All year [h]	Summer period [h]
Standard HSP compound	16.07	2586	2170
Adapted HSP compound	21.13	2634	2172
Low FC compound	16.05	1739	1323
High FC compound	16.12	851	436

3.2.4 Evaluation of heating demand deviations – effects of shading elements

Continuing from the suggestions of the design optimisation to avoid the overheating risk in the buildings, the design and the window parameters in specific are further adapted for an additional detailed evaluation. In contrast to the design optimisation, instead of the previously applied benchmark values product specific values of passive house suitable wood frames and triple layer glazing are used for the window constructions (Ug = 0.47 W/m²K; Uf = 0.91 W/m²K; g-value = 0.52). The calculated heating demands of the buildings for EP+ and GEQ are then compared and analysed in detail, especially regarding deviations caused by the transmitted solar radiation through transparent building elements.

The goal of this section is not to compare the different calculation methods for EP+ und GEQ step by step, which are described in detail in the EP+ Engineering Reference (U.S. Department of Energy, EnergyPlus Engineering Reference, 2017) and in the ÖNORM B8110-5 (Austrian Standards, ÖNORM B8110-5 2019 Wärmeschutz im Hochbau Teil 5: Klimamodell und Nutzungsprofile, 2019), but to give a basic guideline for the effects on the computed results. Therefore, the differences of the transmitted solar radiation between the selected programs are investigated for the project location of Böheimkirchen.

In a first step, the results of a sample window with a transparent surface of 5 m² for both programs are examined regarding the effects of a differing window size, varying orientation due to a clockwise rotation with a step of 22.5° for a total of 16 different directions as well as concerning a lateral shading caused by the building itself in case of the atrium-style buildings and a window overhang. The window overhang includes variations for a length from 0.0 m to 3.0 m with a step of 0.5 m for shading elements attached directly above the window and with heights of 0.33 m as foreseen in the design of the building compound for the GF and of 0.98 m as with the atrium-style buildings. Second, the influencing parameters of the orientation, the window overhang and the lateral shading are also applied for the adapted building designs containing all window elements. Third, the effects of these are evaluated altogether. For an appropriate comparison of the results no mechanic shading devices are applied in this EP+ model, although they are actually foreseen in the building design. The lengths of the overhangs for the adapted building models and the corresponding window directions are displayed in Table 20. The results are compared regarding the transmitted solar radiation for one m² of the transparent surface for the period of one year (kWh/m²a) and regarding the total transmitted solar radiation of the sample window for each month (kWh) to show the tendency throughout the year.

Table 20: Dimensions of window overhangs (in m) and orientation of the adapted building designs

Overhang	**N [m]**	**NNE [m]**	**E [m]**	**EES-1 [m]**	**EES-2 [m]**	**S [m]**	**SSW-1 [m]**	**SSW-2 [m]**	**W [m]**
Compound	2.0	-	4.5	-	-	3.0	-	-	2.8
Atrium East	-	1.3	-	0.7	1.5	-	1.0	1.2	-
Atrium West	-	1.3	-	-	1.5	-	1.0	1.2	-

Based on the different calculation methods of each program, varying results are expected but with similar tendencies for the different building types (Drechsel, 2014). The results displayed in Table 21 show significant differences.

Table 21: Heating demands and transmitted solar radiations for the adapted building designs

Building type/element	**EP+ heating intensity**	**GEQ HWB_SK**	**EP+ – transmitted solar radiation**	**GEQ – transmitted solar radiation**
Compound [kWh/a]	10407.41	9203.00	23761.67	39981.20
Floor/window [m²]	682.08	781.00	155.00	155.00
[kWh/(m²a)]	15.26	11.78	153.30	257.94
Atrium East [kWh/a]	2076.08	2598.00	5504.06	5394.70
Floor/window [m²]	133.31	152.69	31.60	31.60
[kWh/(m²a)]	15.57	17.01	174.18	170.72
Atrium West [kWh/a]	2076.99	2586.00	5146.62	5008.70
Floor/window [m²]	133.31	152.69	29.44	29.44
[kWh/(m²a)]	15.58	16.94	174.82	170.13

For an appropriate comparison of the results and the transmitted solar radiations for the buildings and site, the HWB_SK is used instead of the HWB_RK, which us defining the overall goal for the design optimisation. While the calculated heating demands of the Atrium East and West buildings show the same tendencies with lower values of 15.57 kWh/(m²a) and 15.58 kWh/(m²a) for EP+ in relation to GEQ with values of 17.01 kWh/(m²a) and 16.94 kWh/(m²a), the heating demand of the building compound with 15.26 kWh/(m²a) for EP+ is higher compared to 11.78 kWh/(m²a) for GEQ. Therefore, the results show not only deviations between the calculation programs, but also deviations between different building types within the same software. A first evaluation of the results suggests that these values are strongly dependent on the transmitted solar radiation through the transparent building elements (see also Table 21).

Sample window orientation

To investigate the reasons causing these significant differences of the transmitted solar radiations between the building types and software, the effects on a south-oriented sample window with sizes of 1, 5 and 10 m² are compared first, using the same properties without additional shading elements for both programs. The results suggest that there is a general difference of 239.8 kWh/(m²a) for EP+ to 382.4 kWh/(m²a) for GEQ, because of varying climate data sources. This is a difference of 37 % independent of the window size.

Next, the 5 m² sample window is examined regarding varying orientation due to a clockwise rotation with a step of 22.5° for a total of 16 different directions. The results for the total annual transmitted solar radiation show, accordingly to the prior findings, for all variations higher values for the software GEQ than for EP+, but with a varying difference (see Figure 32). The biggest gap with 142 kWh/(m²a) between the results is for the south-facing sample window, while the smallest difference is with 92 kWh/(m²a) for the north-facing window direction. This behaviour is also reflected in the results for the monthly transmitted solar radiation of the sample window for a clockwise building rotation between 0° and 180° (see Figure 33). It is important to mention that the results for GEQ are mirrored along the north-south axis while the results for EP+ are slightly varying.

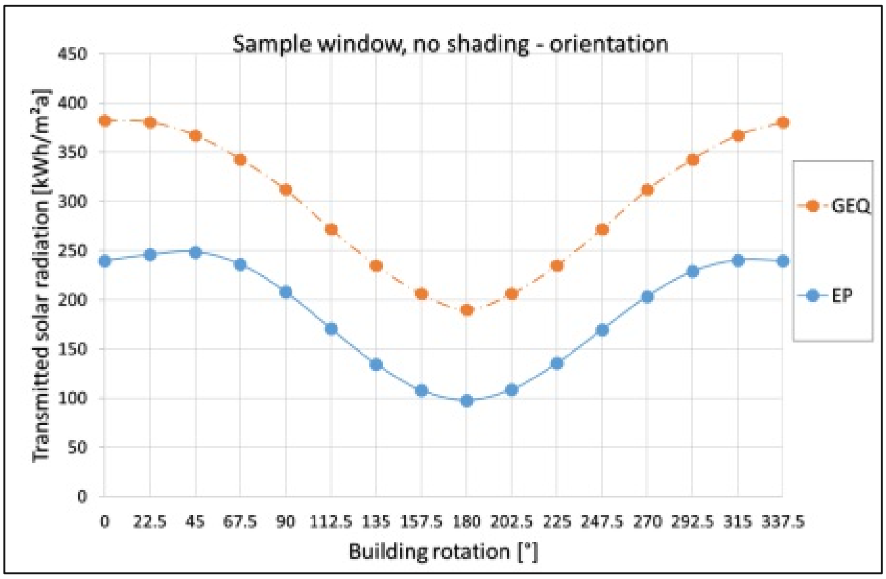

Figure 32: Sample window with varying orientation, no shading: Transmitted solar radiation in kWh/(m²a)

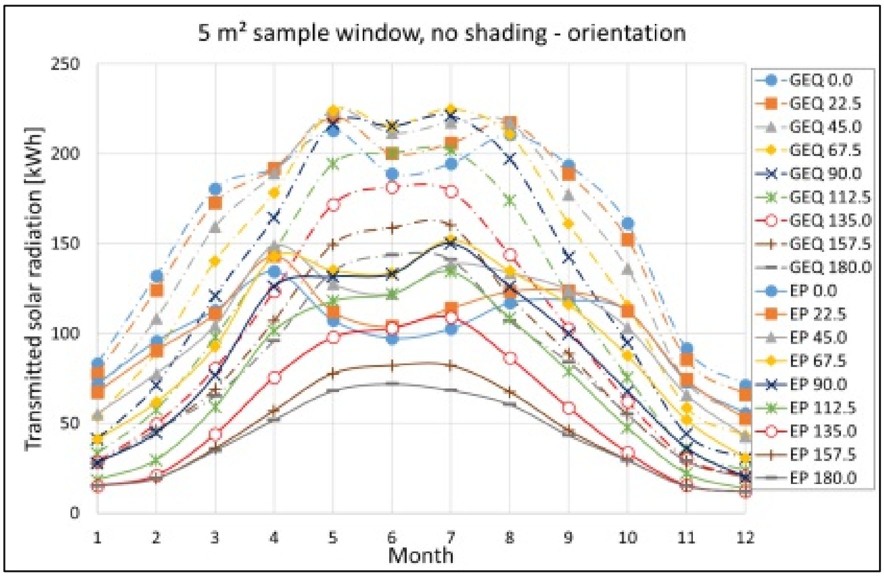

Figure 33: Sample window with varying orientation, no shading: Transmitted solar radiation in kWh

Sample window overhang depth

The causes for the diverging effects of the transmitted solar radiation are subsequently examined in more detail regarding the application of shading elements, in particular a window overhang as well as a lateral shading caused by the building itself in case of the atrium-style buildings.

The results for the transmitted solar radiation of the south-oriented sample window with an overhang are displayed in Figure 34. Similar to the previous investigations the results for GEQ are in general higher than the ones for EP+. The difference between the values decreases from 142 kWh/(m²a) to 68 kWh/(m²a) with an extension of a directly above the window attached overhang shading to a maximum depth of 3.0 m. Due to the use of shading elements, which are attached higher above the window elements than foreseen in the optimised design, also the transmitted solar radiation increases, but with a similar tendency.

Comparing the monthly-transmitted solar radiations, Figure 35 shows that with an increased length of the overhang shading element for EP+ also the differences between the variants decrease. Long shading elements between 2.5 m and 3.0 m show with an average difference of less than 5 kWh/(m²a) almost similar low values for each month throughout the year compared to shorter elements with more than 20 kWh/(m²a), while for GEQ the general tendency with an average difference of approximately 25 kWh/(m²a) remains almost the same.

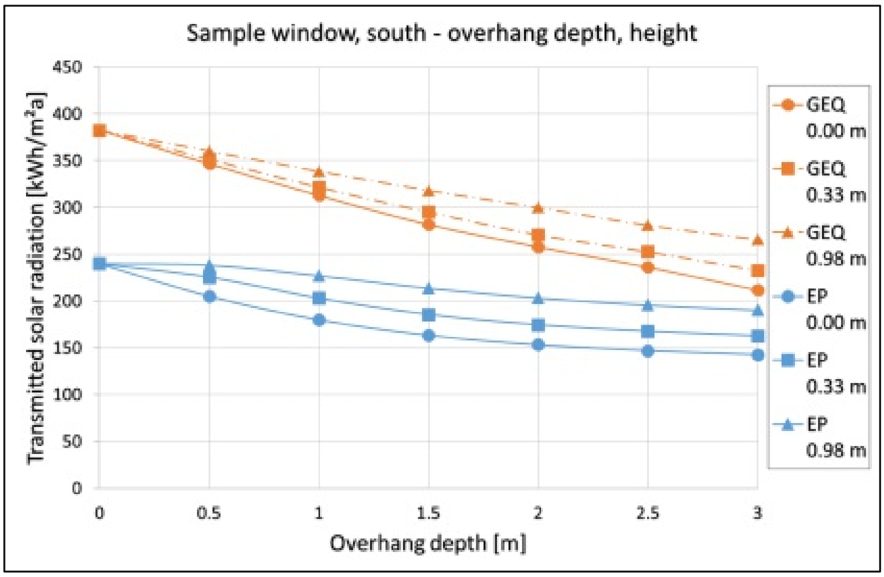

Figure 34 Sample window with varying overhang shading: Transmitted solar radiation in kWh/(m²a)

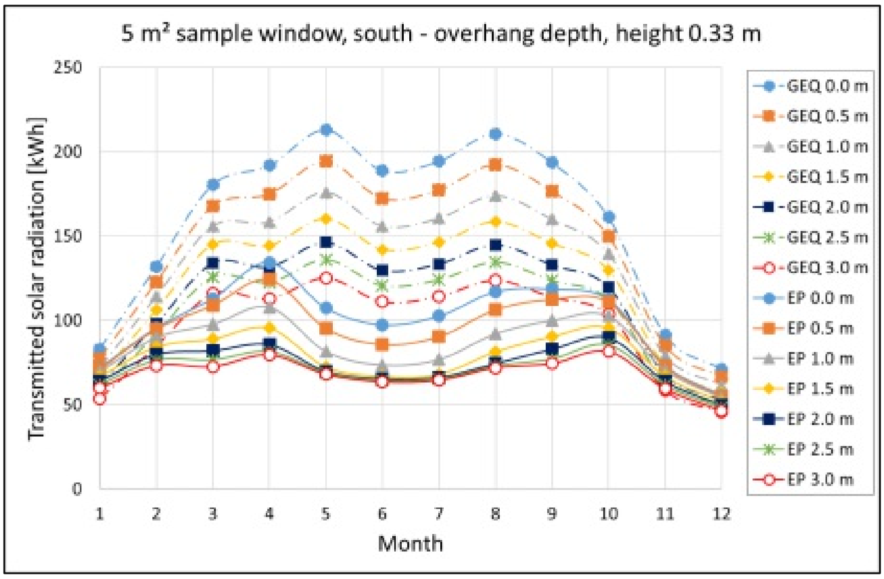

Figure 35 Sample window with varying overhang shading: Transmitted solar radiation in kWh

Sample window lateral shading

The results for the transmitted solar radiation of the sample window concerning a lateral shading caused by the building itself in case of the atrium-style buildings are displayed in Figure 36. A south-oriented position for the sample window is selected facing the courtyard with a distance of 4.1 m to the shade producing wall element with a length of 5.8 m.

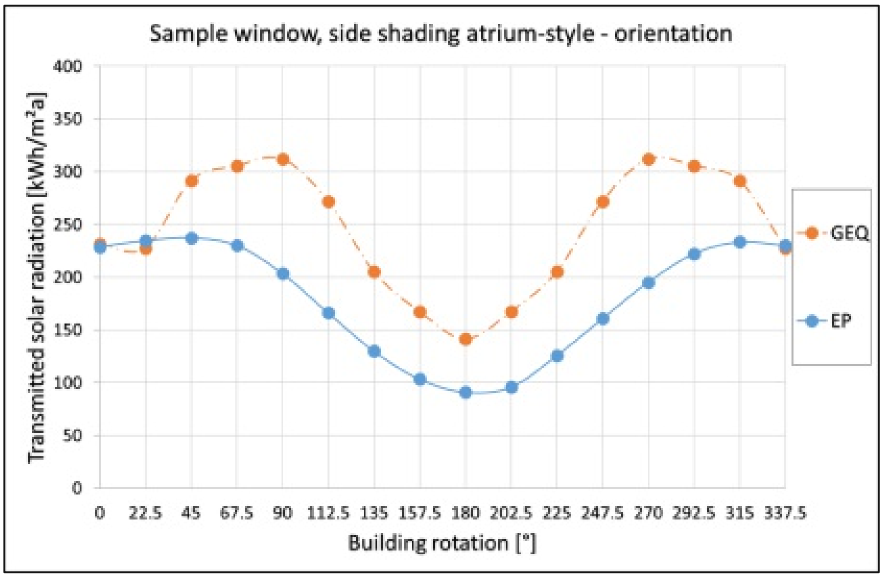

Figure 36: Sample window with lateral shading and varying orientation: Transmitted solar radiation in kWh/(m²a)

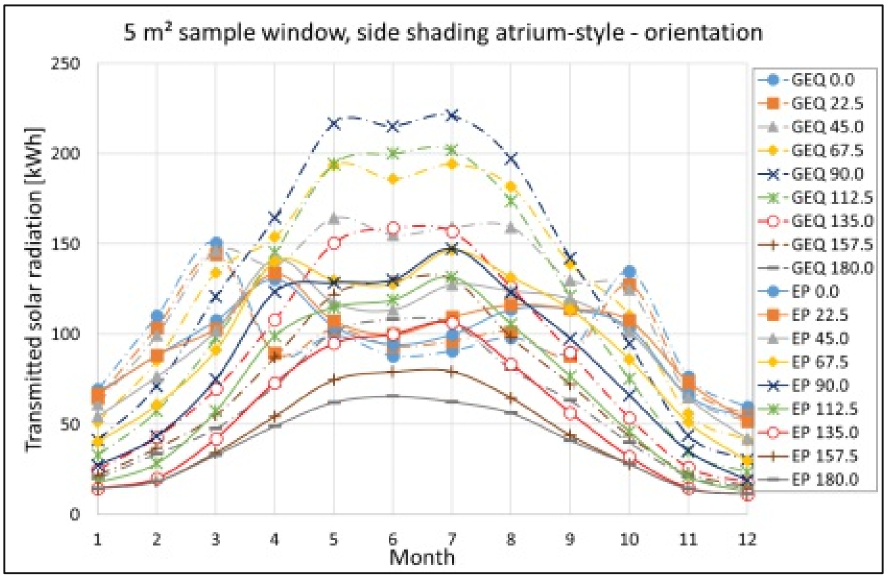

Figure 37: Sample window with lateral shading and varying orientation: Transmitted solar radiation in kWh

The commuted results for the total annual transmitted solar radiation for EP+ show with an average difference of 8 kWh/(m²a) lower values compared to the sample window without any lateral shading impact, although the general tendency of the results remains the same. However, the results for GEQ show significant deviations. First, the results for GEQ are also mirrored along the north-south axis as with the sample window without any shading, caused by the use of simplified shading factors for each window element independent of the buildings actual shape. The fact that the sample window should be shaded from different directions with a varying impact, taking the path of the sun as well as the rotation of the building into account, is not considered in this calculation method. Second, the lateral shading has a comparable high impact on the south-oriented directions from south-south-east to south-south-west resulting in lower total annual solar radiation values than for EP+. This behaviour is also reflected in the results for the monthly transmitted solar radiation of the variants (see Figure 37). The main difference especially occurs in the summer time between April and September, when the results for GEQ of the south-oriented variants decrease below the values for EP+.

Adapted building design

Proceeding from the evaluation of the sample window regarding the influencing parameters of the orientation, the window overhang and the lateral shading, the adapted building designs of the atrium-style buildings and the building compound are also examined in more detail.

The results for the transmitted solar radiation of the adapted building designs are displayed in Figure 38, Figure 39 and Figure 40. Especially the tendencies of the atrium-style building with a lateral shading for a rotation of 22.5° (see Figure 37) are evident. With more than 60 % of the transparent surfaces facing south-south-west, the values of the transmitted solar radiations are with 174 kWh/(m²a) for EP+ higher compared to 170 kWh/(m²a) for GEQ (see Table 21). A simulation without a window overhang results in an even bigger difference of 209 kWh/(m²a) for EP+ compared to 192 kWh/(m²a) for GEQ. Additional shading effects in EP+ from overhangs not only to the windows directly below, but also to other transparent surfaces especially in the corner of the atrium courtyard, influence the results. This effect in EP+, which is not automatically considered in GEQ, leads to a slightly higher transmitted solar radiation, and in further consequence to a lower heating demands for the atrium-style buildings with EP+ compared to GEQ (see Table 21).

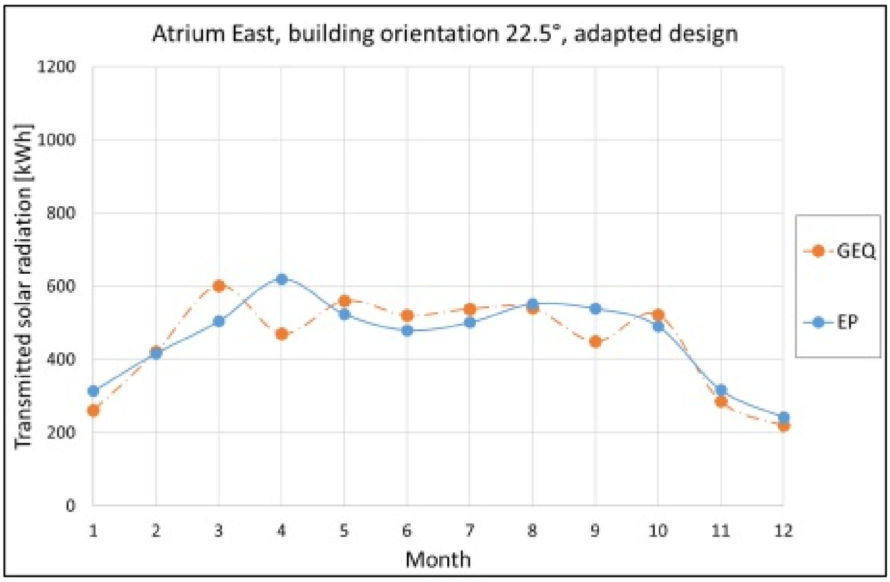

Figure 38: Transmitted solar radiation for the adapted design of the Atrium East building

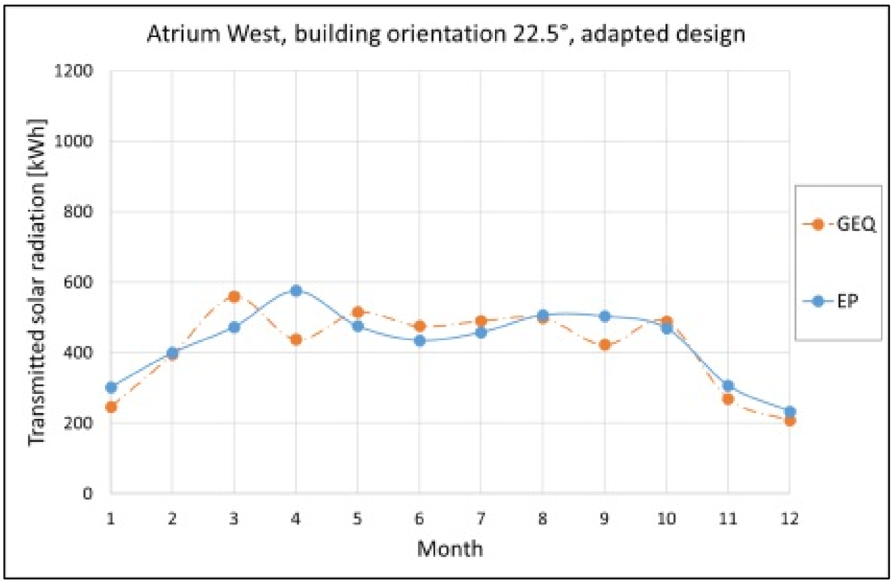

Figure 39: Transmitted solar radiation for the adapted design of the Atrium West building

Likewise the results for the adapted design of the building compound reflect the prior findings for the sample window (see Figure 40). With the buildings original orientation (building rotation of 0°) and without any lateral shading, because of the rectangular building shape, the total transmitted solar radiation is with 39981 kWh/a for GEQ clearly above the calculated value of 23761 kWh/a for EP+, resulting in 257 kWh/(m²a) and 153 kWh/(m²a) (see Table 21).

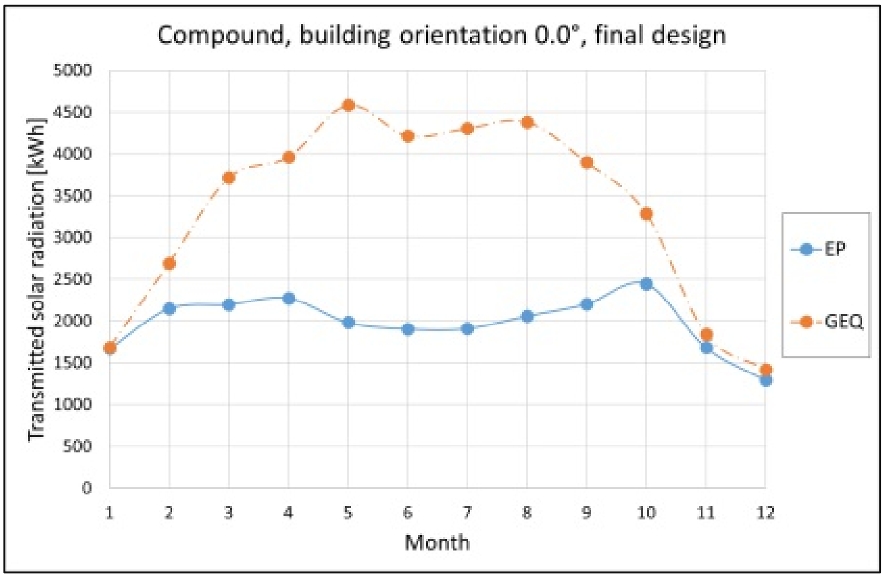

Figure 40: Transmitted solar radiation for the adapted design of the building compound)

3.2.5 Assessment of overheating risk detailed planning permit design

The assessment, as described in chapter 2.4, is conducted for the three selected living units Top 2, 4, and 6 of the building compound (see Figure 22 and Figure 23) as well as for the atrium-style buildings (see Figure 17). Relevant for the approval regarding prevention of overheating in summertime according to the Austrian EPC are all thermal zones containing transparent surfaces. These are for Top 2 the EH and the LK in the GF as well as a HW, three bedrooms (Bed1, Bed2, Bed3), and a bathroom in the UF, while for the smaller Tops 4 and 6 the bedrooms, the bathrooms, the LKs and the storerooms are relevant. For the atrium-style buildings the thermal zones Bed1, Bed2, Bed3 and the LK is investigated. For these spaces the minimum required settings, in specific time controlled exterior shades for the individual windows, are applied in a first step for the building model in GEQ necessary for approval of the simulation method. These settings are then applied to the suggested EP+ building model and compared with the findings of GEQ including an assessment of the outdoor air temperatures.

The results show that additional measures are necessary for individual thermal zones to fulfil the requirements of the Austrian standards for the suggested building models. The approval can be achieved by use of time-controlled external shading devices. An overview for the areas to be examined, the individual windows and the required operation time is provided in Table 22. The results show that especially for the south-oriented windows additional shading is needed to achieve an adequate thermal comfort in summertime for the occupants. Also the east-oriented windows of Top 4 and 6 are showing some divergences, while the windows in the UF are shaded by the extended roof, an additional mechanical shading is required for the ones in the GF.

Table 22: Minimum required approval settings for prevention of overheating for the building compound

Building	**Compound Top 2**											
TZ	LK					EH	Bed1		Bed2		Bed3	Bath
Floor	GF	GF	GF	GF	GF	GF	UF	UF	UF	UF	UF	UF
Window	N3	S5	S6	S7	S8	N4	S5	S6	S7	S8	N4	N5
Orien.	N	S	S	S	S	N	S	S	S	S	N	N
Ext. shades [time]	-	11-15	11-15	11-15	11-15	-	11-16	11-16	11-16	11-16	-	-
Building	**Compound Top 4**											
TZ	LK						Bed		SR	Bath		
Floor	GF	GF	GF	GF	GF	GF	GF	GF	GF	GF		
Window	N12	E1	E2	S18	S19	S20	S16	S17	N10	N11		
Orien.	N	E	E	S	S	S	S	S	N	N		
Ext. shades [time]	-	08-16	08-16	09-17	09-17	09-17	09-17	09-17	-	-		
Building	**Compound Top 6**											
TZ	LK						Bed		SR	Bath		
Floor	UF	UF	UF	UF	UF	UF	UF	UF	UF	UF		
Window	N14	E1	E2	S18	S19	S20	S16	S17	N10	N11		
Orien.	N	E	E	S	S	S	S	S	N	N		
Ext. shades [time]	-	-	-	10-16	10-16	10-16	11-16	11-16	-	-		

Table 23: Minimum required approval settings for prevention of overheating for the Atrium buildings

Building	**Atrium East**									
TZ	Bed1			Bed2		Bed3	LK			
Window	S1	S2	E1	S1	S2	S1	E1	E2	E3	S1
Orien.	SSW	SSW	ESE	SSW	SSW	SSW	ESE	ESE	ESE	SSW
Ext. shades [time]	12-16	12-16	-	14-15	-	-	-	-	-	-
Building	**Atrium West**									
TZ	Bed1			Bed2		Bed3	LK			
Window	S1	S2		S1	S2	S1	E1	E2	E3	S1
Orien.	SSW	SSW		SSW	SSW	SSW	ESE	ESE	ESE	SSW
Ext. shades [time]	-	-		14-15	-	-	-	-	-	11-15

In the next step the climate conditions of the different software, in specific the outdoor air temperatures, are examined for a unified comparison. In contrary to the Austrian EPC, for which the repeating outdoor air temperature of the 15th of July is used for the simulation, the climate data used for the location of Böheimkirchen with EP+ is showing a comparable cold day with low temperatures and therefore not representative. Instead, the average hourly temperatures for July are considered (see Figure 41).

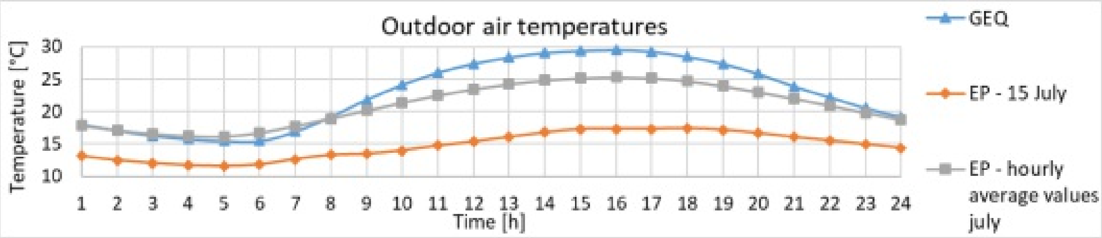

Figure 41: Comparison of the outdoor temperatures

For the assessment of the results in EP+, the required external shades and operation times (see Table 22) are then applied to the building model together with natural ventilation during night. According to the Austrian standards, the windows have to be kept open between 22 pm an 6 am, if the outdoor air temperature is below the indoor temperatures, which is applicable for all examined spaces, while for all other times a specific hygienic air flow volume of 1.411 m³/m²h is applied. The results for Top 2 of the building compound are displayed in the following Figure 42 and Figure 43, while the ones for Top 4 and 6 are shown in the appendix (see Figure 98, Figure 99, Figure 100 and Figure 101). The results of the atrium-style buildings are as well displayed in the appendix (see Figure 102, Figure 103, Figure 104 and Figure 105). For the outdoor air temperatures also the hourly average indoor temperatures of the individual thermal zones for July in EP+ are considered in order to be comparable with the results of GEQ.

All computed results show similar tendencies. Corresponding to the larger variation between day and night time outdoor temperatures of the location, which are caused by the used repeating temperature of the 15th of July, also the operative temperatures of the individual thermal zones show for GEQ a wider variation, especially the spaces with large building openings, compared to temperatures of EP+. The results with EP+ therefore are less affected by the varying day and night time temperature differences and show more constant values throughout the day.

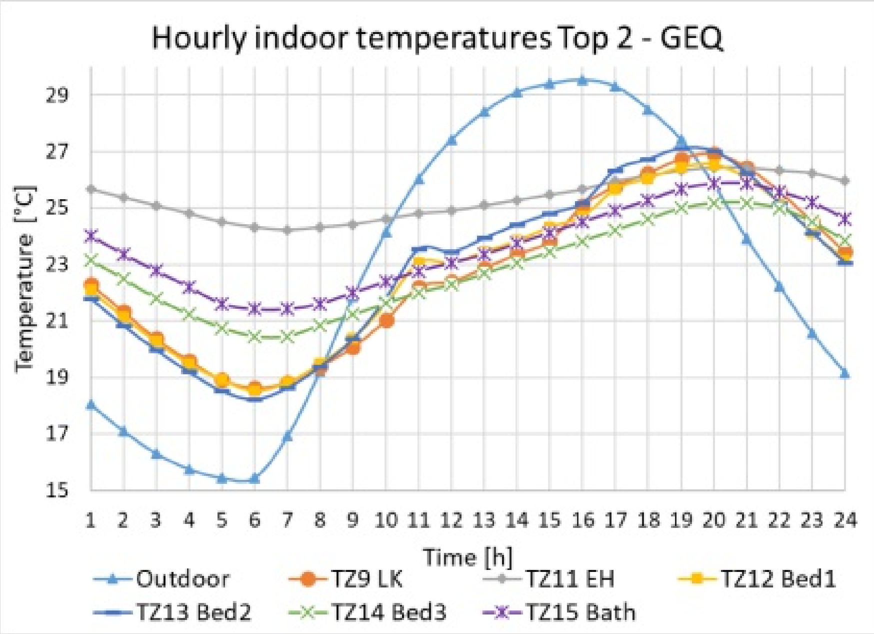

Figure 42: Indoor temperatures of Top 2 for GEQ

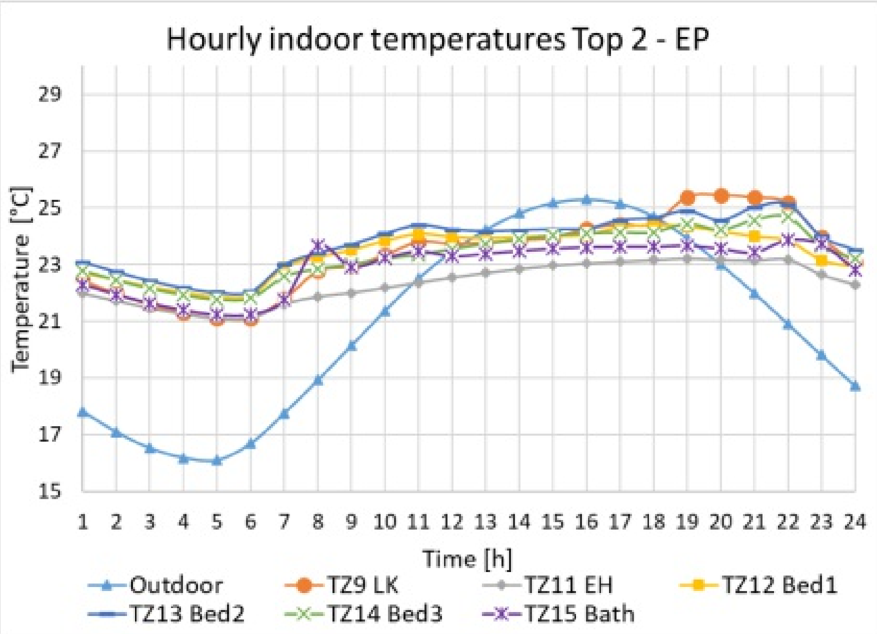

Figure 43: Indoor temperatures of Top 2 for EP+

It is also important to mention that the operating temperatures of the indoor environments for the living units of the building compound of both software are in average on the same temperature level, considering that the outdoor peak temperatures during the hottest period of the day, which are used for GEQ in accordance with the Austrian standards, are up to 5 °C above the ones used for the calculation with EP+. In contrary, the temperatures of the indoor environments of the atrium buildings show higher values, reflecting also the observed effects derived by the deviations of the varying solar radiations.

Furthermore, the simulation with EP+ was done over the timespan of the entire year, even if for the assessment for prevention of overheating in summer only the findings of July are used, to include the influence of warmer or cooler prior outdoor conditions and their effect on the indoor environment, which is not considered for GEQ. Due to the use of lightweight construction building elements the deviation in this case is in average 0.1 °C only. While in contrary also the occupants´ behaviour in EP+, e.g. in case of the bathroom, show bigger impacts on the indoor temperatures.

3.2.6 Final planning permit building design

Proceeding from the developments during the detailed planning permit phase the adapted designs of the buildings and the overall layout of the construction site are displayed in Figure 44 and Figure 45.

Figure 44: Design of the buildings for the planning permit (Arch. Scheicher)

Independent of the suggestions for the individual building types and due to modifications for the energy system, the location of some components of the system in specific on the supply side are going to be installed in an additional room for technical installation next to the carports. Beside the central energy system located in the building compound. Positive side effects of the modified carport construction are that the available space within the building compound to be used for living units is slightly increased, while at the same time the TR in the building compound is accordingly reduced, and that in case of a micro biomass CHP plant the operation and maintenance can be done without disturbing the residents. The CHP will be combined with solar collectors and photovoltaic panels. An efficiency of 85 % for the ventilation system is considered for all living units. Furthermore, another positive side effect is that the carport construction functions also like a noise protection barrier between the living units and train station located close-by.

Figure 45: Site plan with building compound, atrium-style houses and carports for the planning permit (Arch. Scheicher)

Atrium buildings

For the final planning permit design (FPPD) of the atrium-style buildings, the modifications described in chapter 3.2.2 regarding the optimisation of the window width and orientation (see also Table 7) as well as the use of solar tubes have been considered together with the adaption of the room layout (see Figure 46).

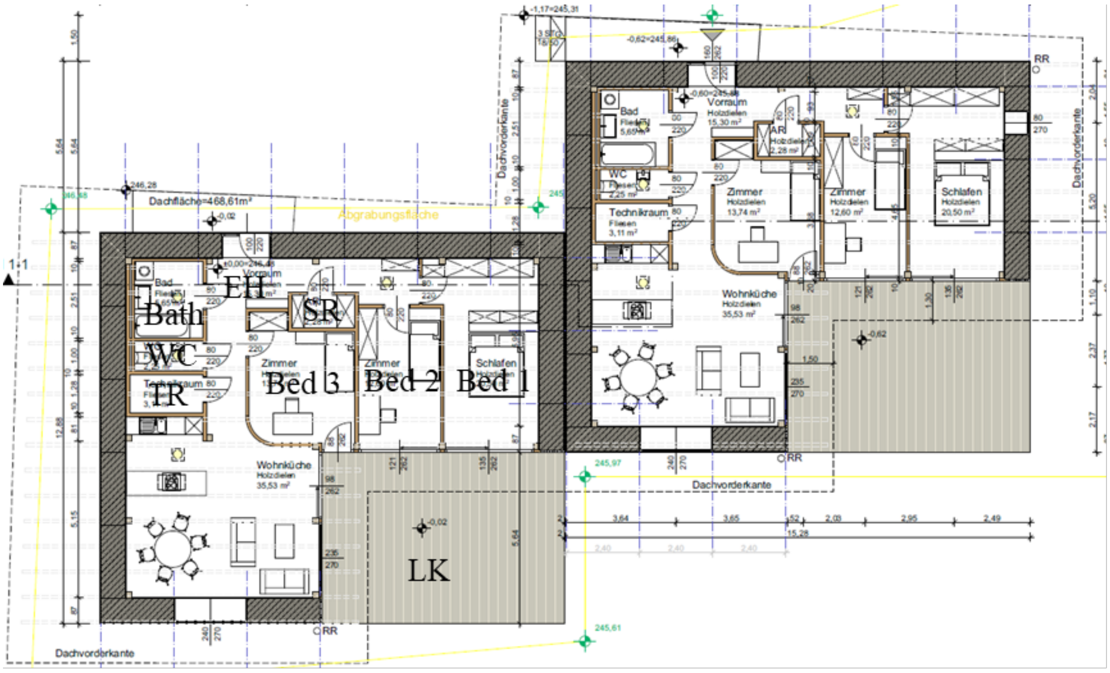

Figure 46: Floor plan of atrium-style buildings for the planning permit (Arch. Scheicher)

Regarding the shading design optimisation (see also Table 12) the suggestion for the east-east-south oriented transparent surfaces facing the courtyard (EES-2) has been considered with an overhang of 1.5 m together with the south-south-west oriented windows (SSW-1 and SSW-2) with an overhang depth of 1.3 m for a unified roof design and connection of the two buildings (see Figure 47). The overhang depth for the east-east-south oriented windows (EES-1) has been extended to 1.7 m in contrary to the suggestions because of design and weather protection reasons. The triangle-shaped roof edge to the remaining cardinal direction has been selected by choice of the Architect.

Table 24: Overhang depth variables for the FPPD

Building	**NNE [m]**	**EES-1 [m]**	**EES-2 [m]**	**SSW-1 [m]**	**SSW-2 [m]**
Atrium East	1.3	1.7	1.5	1.3	1.3
Atrium West	1.3	-	1.5	1.3	1.3

Furthermore, also the described adaptions of the construction materials, which are leading to an increased performance of the building envelope (exterior wall=0.06 W/m²K; roof=0.06 W/m²K; floor=0.05 W/m²K) and to a reduction of the wood elements for a less resource-intense construction, have been applied to the FPPD. The detailed constructions and values are displayed in Table 53, Table 54, Table 55 and Table 56 in the appendix. These are combined with passive house suitable wood frames and triple layer glazing using the product specific values (see also section 3.2.4) for the window constructions (Ug = 0.47 W/m²K; Uf = 0.91 W/m²K; g-value = 0.52).

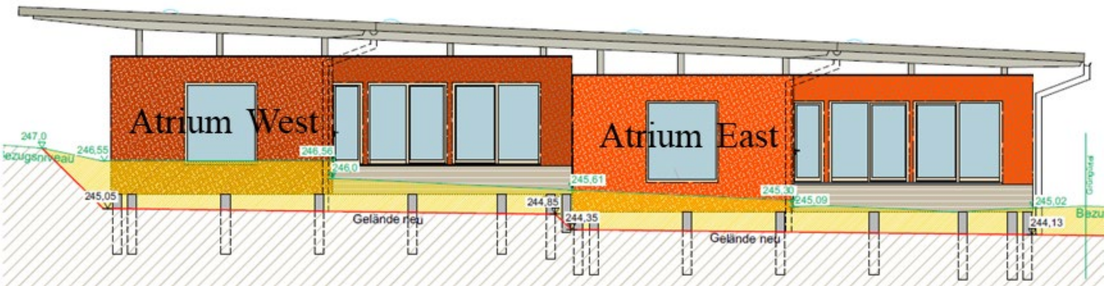

Figure 47: South view of the atrium-style building for the building permit (Arch. Scheicher)

Building Compound

The size of the GFA of the FPPD for the building compound remains the same with slight variations for the room layout, because of the reduced centralised room for technical installation see Figure 48 and Figure 49 for the general modification of the GF and UF and because of the optimised layout for the sanitary equipment similar as for the atrium-style buildings.

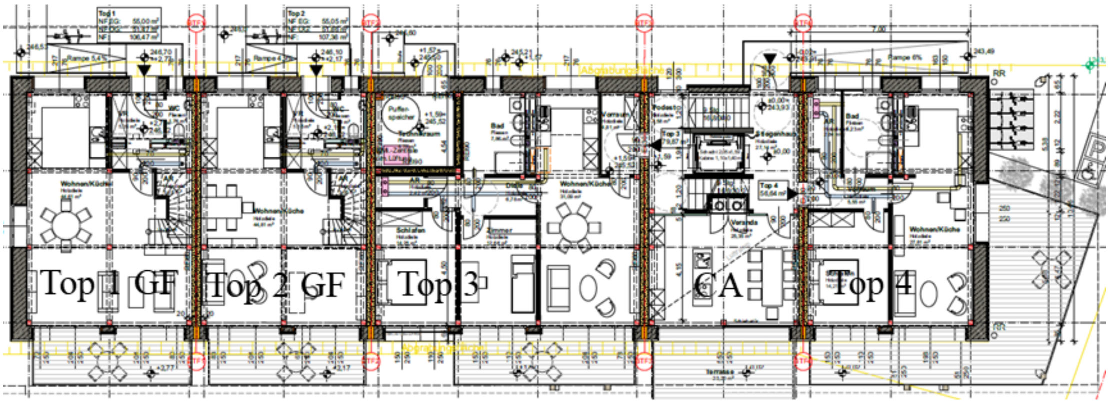

Figure 48: Floor plan (GF) of the building compound for the planning permit (Arch. Scheicher)

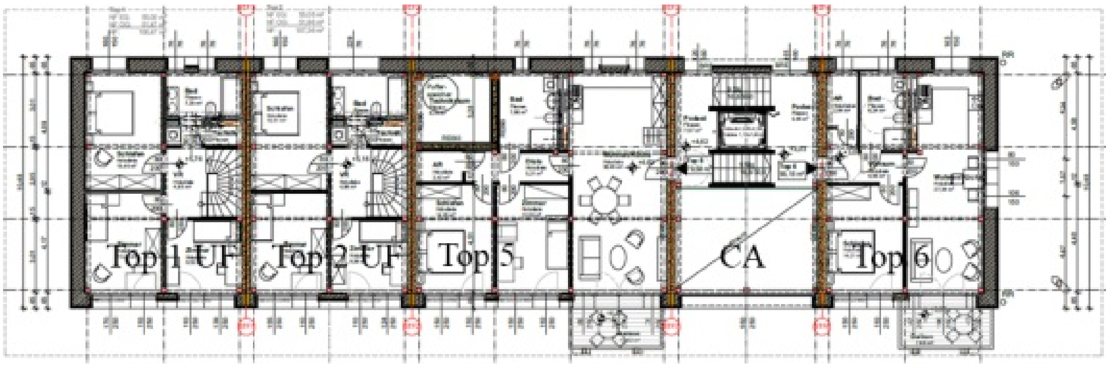

Figure 49: Floor plan (UF) of the building compound for the planning permit (Arch. Scheicher)

In addition to the modification of the room layout and sizes, an additional room for technical installation in the UF for the living units in town house style is needed. Furthermore, for unification and a modular design an additional storeroom has been integrated at the same position in the GF. See Figure 50 and Figure 51 for the adaptions of Top 2, Top 4 and Top 6 in specific. While Top 3 and Top 5 have now the same size and layout with 2 bedrooms and a combined bathroom with WC. The only difference is the EH for Top 5, effecting in a smaller kitchen area compared to Top 3. See also Figure 48 and Figure 49.

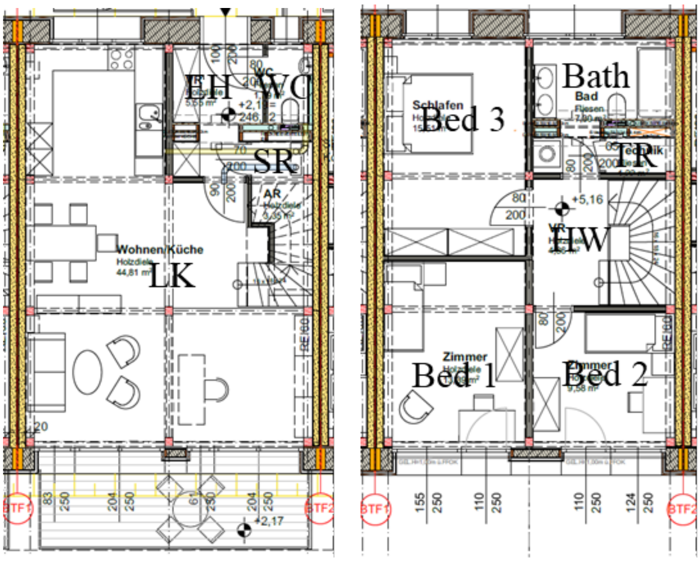

Figure 50: Left: Floor plan Top 2 GF; right: Top 2 UF for the planning permit (Arch. Scheicher)

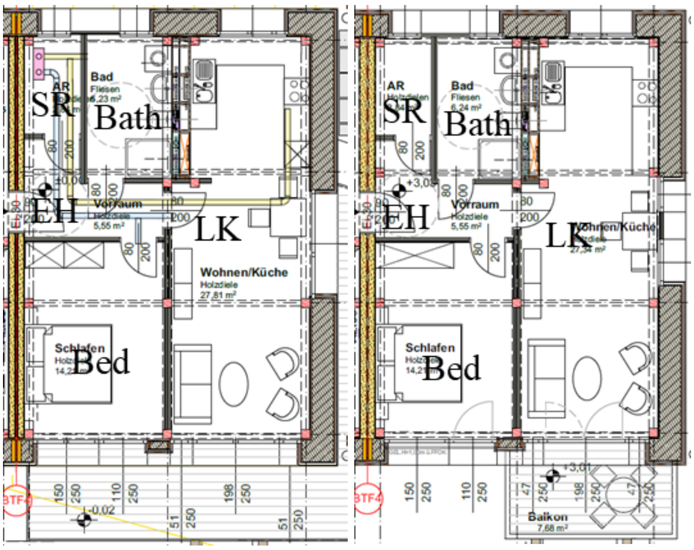

Figure 51: Left: Floor plan Top 4 GF; right: Top 6 UF for the planning permit (Arch. Scheicher)

Regarding the shading design optimisation for the building compound (see also Table 15) the suggestions for the depth of the south oriented roof overhang and the depths and width of the balconies have not been integrated in the FPPD (see also chapter 3.2.8). Instead, the parameters of the prior design with a south oriented roof overhang of 2.0 m have been maintained, since the heating demands of all examined variants for the building compound including the prior design are within the threshold-value (see Table 25).

Table 25: Roof and balcony variables for the final planning permt design of the building compound

Variable	North	East	South	West
Roof depth [m]	2.0	4.5	2.0	2.8
Balcony depth Top 3 [m]	-	-	1.7	-
Balcony depth Top 4 [m]	-	-	1.7	-
Balcony length Top 3 [m]	-	-	3.9	-
Balcony length Top 4 [m]	-	-	3.9	-

An exception is the position and width for the balcony of Top 5, because of a modified room layout for this apartment. In place of extending the balconies in the UF or even having a loggia-style for the building to further increase the thermal comfort, a French window style was selected (see Figure 52).

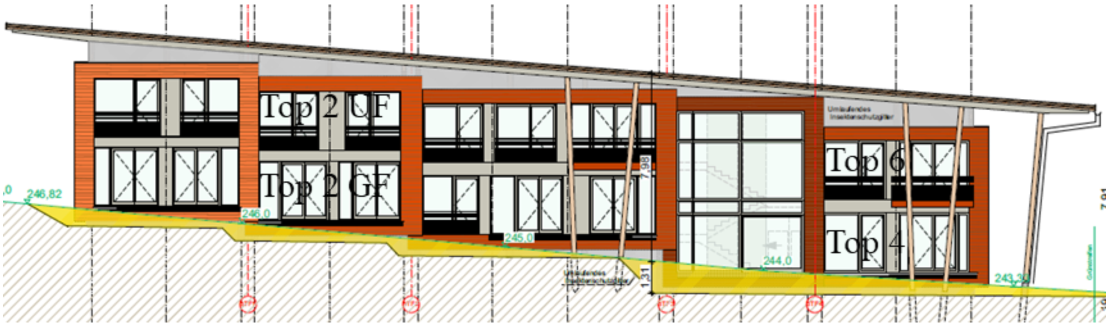

Figure 52: South view of the building compound for the planning permit (Arch. Scheicher)

For achieving a less resource-intense wood construction, some adaptions of the building elements have been implemented. Furthermore, because of building regulations regarding the height of the building, the straw bale insulation layer for the roof has been reduced from 70 cm to 35 cm, with the result of increased u-values for the specific elements of the building envelope (exterior wall=0.10 W/m²K; roof=0.12 W/m²K; floor=0.10 W/m²K). The detailed informations for the building elements of the building compound are displayed in Table 71, Table 72 and Table 73 in the appendix. Same like for the atrium-style buildings the constructions are combined with passive house suitable wood frames and triple layer glazing using the product specific values (Ug = 0.47 W/m²K; Uf = 0.91 W/m²K; g-value = 0.52).

3.2.7 Results for the final planning permit design

The results for the FPPD of the atrium-style building and the building compound, submitted to the building authority, are displayed in the following subchapter. These include the total number of hours with indoor temperatures above 26 °C for the evaluation of the indoor environment of the individual zones and total buildings as well as the heating demands and intensities calculated for EP+ and GEQ.

Atrium buildings

The results for the FPPD of the atrium-style buildings are showing some differences compared to the results of the suggested optimised building design displayed in chapter 3.2.2 because of the adaption described in chapter 3.2.6. Due to the use of more appropriate glazing components from the IGDB (see also chapter 3.2.4) and the increased transmitted solar radiation through the transparent building elements the total numbers of hours with indoor temperatures above 26 °C are increased for all individual zones of the atrium-style buildings (see Table 26). Resulting in a total of 2378 h for the Atrium East building and 2275 h for the Atrium West building.

Table 26: Time with indoor temperatures > 26 °C for zones of the FPPD of the atrium-style buildings

Building	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	LK [h]	WC [h]	Bath [h]	Zones 1-8 [h]
Atrium East	1865	2119	1405	1120	1032	2078	954	833	2378
Atrium West	1572	1998	1355	1029	951	2011	941	820	2275

Accordingly, the total numbers of hours with indoor temperatures above 26 °C for the different scenarios of the atrium-style buildings are in general increased, but with similar tendencies like the prior suggested building designs. The following Table 27 is showing an overview of the results for the standard HSP, the adapted HSP, the low FC and the high FC scenarios of the FPPD for the atrium-style buildings for the period of a whole year and for the summer period only.

Table 27: Time with indoor temperatures > 26 °C for scenarios of the FPPD of the atrium-style buildings

Building and period	Standard HSP [h]	Adapted HSP [h]	Low FC [h]	High FC [h]
Atrium East	2378	2407	1497	825
Atrium East summer period	1818	1831	937	266
Atrium West	2275	2292	1397	774
Atrium West summer period	1769	1775	891	269

The heating intensities for the FPPD of the atrium-style buildings are showing similar values close to the threshold value of 15 kWh/(m²a) for the HWB_SK of the Austrian EPC, because of a slight increase of the shading elements and optimisation of the building elements. The results of the heating intensities of the atrium-style buildings are summarised in the following Table 28.

Table 28: Heating demands of the FPPD of the atrium-style buildings

Building	GEQ HWB_RK	GEQ HWB_SK	EP+ Standard HSP	EP+ Adapted HSP	EP+ Low FC	EP+ High FC
Atrium East [kWh/a]	2007	2297	1909.32	2793.78	1906.44	1917.45
Atrium East [kWh/(m²a)]	13.23	15.14	14.33	20.96	14.30	14.39
Atrium West [kWh/a]	1989	2270	1909.26	2823.67	1906.21	1917.42
Atrium West [kWh/(m²a)]	13.11	14.97	14.33	21.19	14.30	14.39

With a GFA of 152 m², an A/V of 0.77 1/m and a lc of 1.31 m, the atrium-style buildings show calculated values of 13.23 kWh/(m²a) for the HWB_RK and 15.14 kWh/(m²a) for the HWB_SK of the Atrium East building and 13.11 kWh/(m²a) for the HWB_RK and 14.97 kWh/(m²a) for the HWB_SK of the Atrium West building.

This is also reflected in the results for the calculated heating intensities of the FPPD with EP+. Together with the application of the more appropriate glazing elements and the effect of an increased transmission of the solar radiation, the adaptions of the design are resulting in lower heating intensities of 14.33 kWh/(m²a) for the models of the atrium-style buildings in EP+. Accordingly, also the results for the heating intensities of the adapted HSP, the low FC and the high FC are varying.

Building Compound

The results for the FPPD of the building compound is also like for the atrium-style buildings reflecting the adaptions of the building design. With values of 2756 h for Top 2, 2773 h for Top 4 and 2515 h for Top 6 also the total numbers of hours with indoor temperature above 26 °C are increased for the building compound. First, owing to the use of the more appropriate glazing components from the IGDB for EP+ instead of the average benchmark values (see also chapter 3.2.4). Second, and in further consequence because of the increased transmitted solar radiation through the transparent building elements. Third, because of the reduced shading of the south-facing windows. The values for the individual zones of the living units are displayed in the following Table 29.

Table 29: Time with indoor temperatures > 26 °C for zones of the FPPD of the compound

Living unit	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	All [h]
Top 2	2454	2695	1394	891	787	1183	1751	1176	1481	2756
Top 4	2556	-	-	1948	1717	-	2181	-	1962	2773
Top 6	2389	-	-	1289	1446	-	1814	-	1633	2515

In line with this, also the total number of hours with indoor temperatures above 26 °C for the entire building with the standard HSP and for the scenarios of the adapted HSP, the low FC and the high FC have increased correspondingly. An overview of the results for the examined living units and the entire building is provided in Table 30 for the period of a whole year, but also for the summer time from the 1st of May until the end of September.

Table 30: Time with indoor temperatures > 26 °C for scenarios of the FPPD of the compound

Hours with temperatures > 26 °C for all zones per living unit	Standard HSP [h]	Adapted HSP [h]	Low FC [h]	High FC [h]
Top 2 All year	2756	2816	1744	1027
Top 2 summer period	1987	1991	975	258
Top 4 All year	2773	2821	1935	985
Top 4 summer period	2173	2180	1334	385
Top 6 All year	2515	2551	1508	775
Top 6 summer period	1971	1978	964	231
Compound	2996	3080	2154	1204
Compound summer period	2179	2186	1337	387

As a result of the building element adaptions and the increased U-values for the exterior wall and especially for the reduction of the roof isolation, the heating demand according to the Austrian EPC is increased for the building compound. The building is showing calculated values of 11.05 kWh/(m²a) for the HWB_RK and 12.89 kWh/(m²a) for the HWB_SK with a GFA of 769 m², an A/V of 0.55 1/m and a lc of 1.83 m. These results, which are above the initial threshold value, are displayed in the following Table 31.

Table 31: Heating demands of the FPPD of the compound

Building	GEQ HWB_RK	GEQ HWB_SK	EP+ Standard HSP	EP+ Adapted HSP	EP+ Low FC	EP+ High FC
Compound [kWh/a]	8494	9911	10789	13813.54	10779.38	10828.69
Compound [kWh/(m²a)]	11.05	12.89	16.00	20.48	15.99	16.06

Same like for the atrium-style buildings, the design adaptions are also reflected in the EP+ results for the FPPD of the building compound. Due to the increased transmission of solar radiation and because of increased U-Values for the building elements, the with EP+ calculated heating intensity is showing with 16.00 kWh/(m²a) for the standard HSP model almost identical values as for the suggested building design (see chapter 3.2.3). The results for the adapted HSP, the low FC and high FC scenarios are varying accordingly.

3.2.8 Workflow detailed planning permit stage

Continuing from the results of the early design stage and the suggestions for optimised design of the atrium-style buildings as well as the building compound, the starting point for the detailed planning permit stage is the initial planning permit design (see also Figure 5 for the overall optimisation process).

Mainly the project management team, supported by technical experts, conducts the optimisation of the buildings design in this stage towards the FPPD. The technical experts are responsible for the statics, the electrical design and the acoustic protection for the completion of a functionally building design, which is to be used for the tendering process with the construction companies. The system boundaries for the workflow of the detailed planning permit stage are displayed in the following Figure 53.

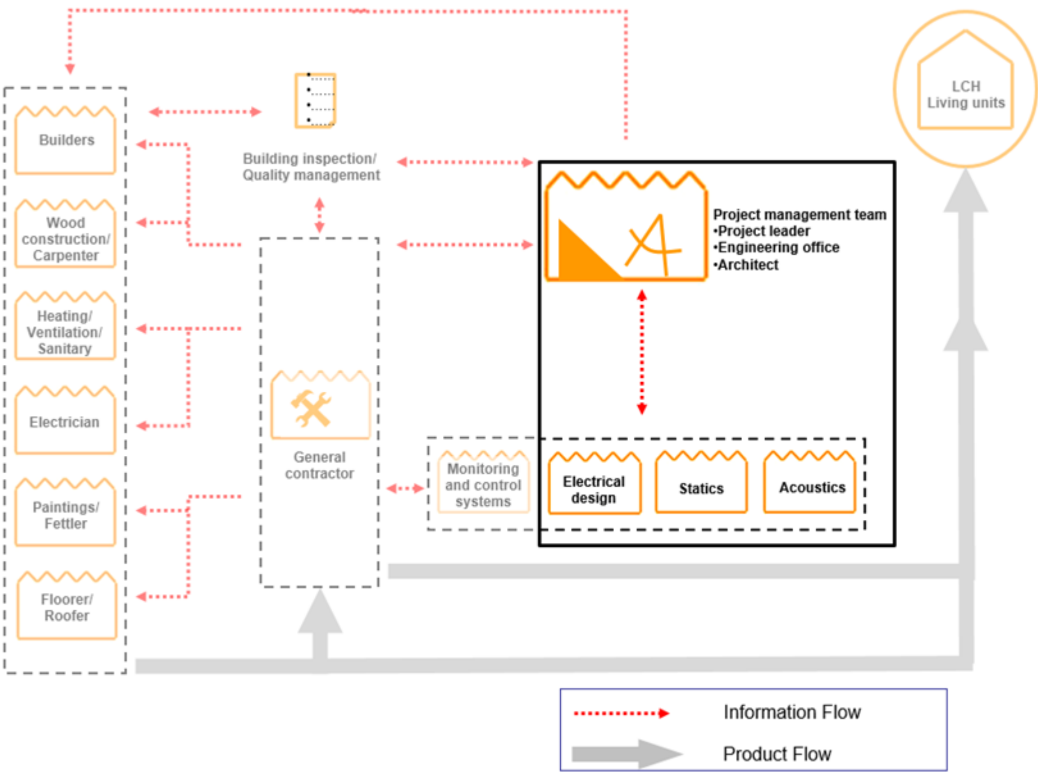

Figure 53: Workflow of the detailed planning permit stage

Same like for the early design stage, the optimisation with the described methods (see chapter 2.3.2) was performed in a circular approach for the atrium-style buildings and in a single linear approach for the building compound, as described in the result chapters 3.2.2 and 3.2.3 of this stage, to be finalised in the planning permit building designs (see chapter 3.2.6).

Also in this design stage, the communication is taking place on demand via email, phone conference or meeting between the members of the project management team, while the supporting activities of the external experts are being executed on invitation only.

A significant difference in this stage is that, compared to the early design stage, the optimisation was carried out with the focus on two key PIs instead of one: the heating demand and the overheating risk of the buildings. As these two key PIs are acting in opposing directions, a parametric optimisation has been used, resulting in not only one but in a range of improved building models depending on the different combination possibilities for the selected variables.

The project leader’s individual preferred design solutions have been integrated in the final planning permit building design. These are contributing in a great measure in achieving the threshold values of the PI´s, like the depth of the south-facing roof overhangs for the atrium-style buildings.

Likewise, also for the partners the option was given to select preferred design solutions of the suggested building models in order not to restrict the personal design flexibility, especially for the architectural point of view. This procedure has been implemented only marginal e.g. for the design of the building compound. Since the results for all examined variants including the initial design are within the threshold-value, a revision of the building design has been in general refused at this stage, if not required, even if a modified design would lead to an increased performance in terms of the key PIs. Instead, it was suggested to focus first on the noise protection requirements, which are quite challenging especially for the apartments in the building compound because of the foreseen wooden skeleton construction. The goal was to develop a base model fulfilling all demands for a building permit approval. The modification of the construction plans regarding shading devices and other minor deviations could be realised in the next planning stage. It was important not to exceed the foreseen working load in case of major required adaptions by the building authority, e. g. the building height regulation for the construction site limiting the thickness of the floors and ceilings not to outreach the maximum building height allowed.

3.3 Final building design stage

3.3.1 Building parameters final design stage

For the final building design stage the starting point is the final planning permit building design (see chapter 3.2.6). In this final optimisation approach the design of the buildings is further adapted, basically regarding a number of cost-efficiency measures as described in chapter 2.3.3. In collaboration with the building companies, the goal was to maintain a high energy-efficiency and to achieve the envisaged construction cost. These adaptions are covering alternative products and less expensive components, a unification of the building elements, a simplification for the manufacturing process as well as some adaptions of the architectural design. The calculation methods for the Austrian EPC remain the same. Also the parameters for the EP+ building models (as described in chapter 3.2.1) remain valid with some modification caused by the adapted room layout (see chapter 3.3.2). A detailed overview for the occupancy, the activity levels, the internal gains of the equipment and for the installed lighting power of the FBD is provided in Table 85, Table 86, Table 87, Table 88 and Table 89 in the appendix.

3.3.2 Final building design stage

Taking into account the progress during this final design stage, the adapted overall layout of the construction site is displayed in the following Figure 54.

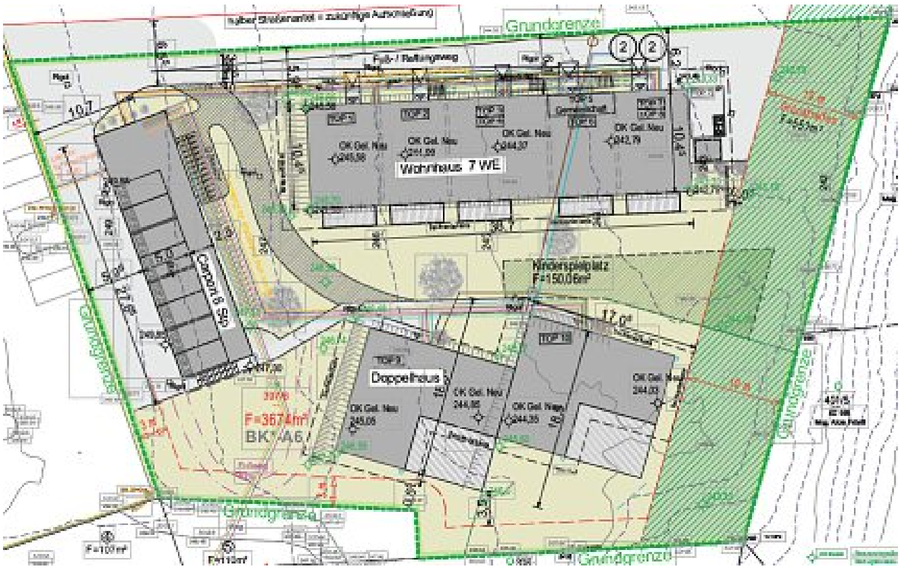

Figure 54: Site plan for the FBD of the building compound, the atrium-style houses and the carports (Arch. Scheicher)

Apart from the optimisation of the living units, there have been some adaptions for the infrastructure and open space design of the construction site, in specific regarding water supply, sewage hook-up, pathways and the roof design of the TR next to the carports to integrate solar collectors with the desired angle for a high efficiency factor.

Atrium buildings

Continuing with the building optimisation in the final stage, in collaboration with the construction companies and considering the required cost optimisation, there have been some modifications for the atrium-style buildings complementing the final FPPD and the FBD.

The general layout of the building and also the GFA remain the same, while some amendments for the room layout have been necessary (see Figure 55). Due to an overall optimised housing technology system, the required space for technical installations could be reduced to a minimum. As a result, a room especially for technical installations is no longer required. Accordingly, the atrium-style building consists of 8 thermal zones instead of 9. The remaining components are mainly integrated in the bathroom, which is significantly enlarged. The separation wall between WC and bathroom is also removable for an optional barrier-free merging of the rooms. Furthermore, the rounded wall between Bed 3 and the LK has been straightened.

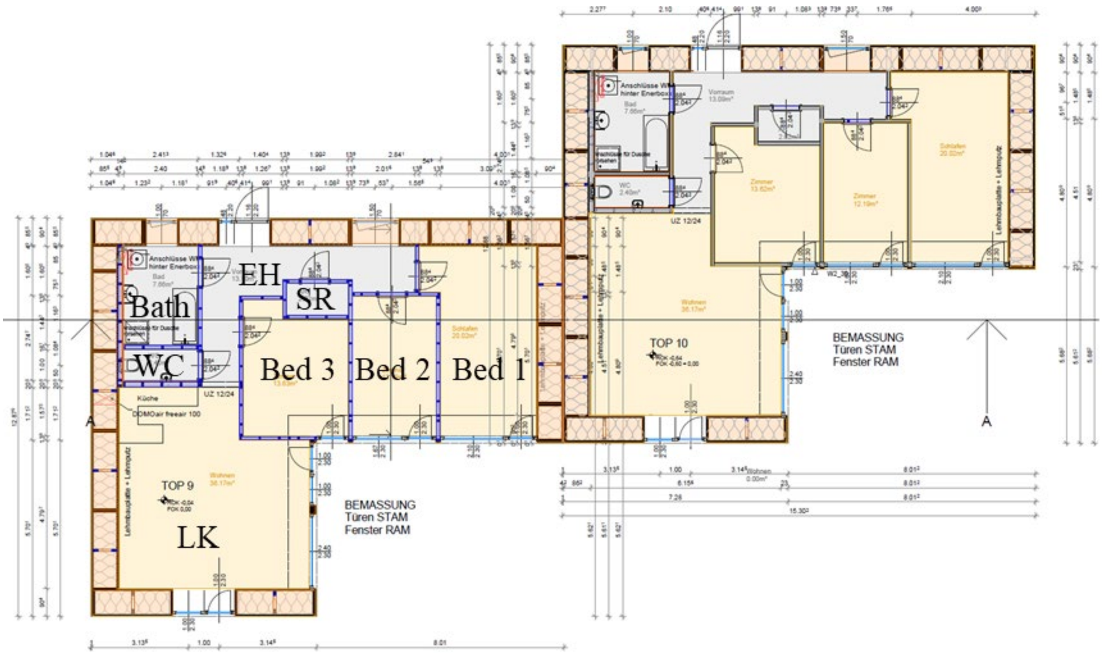

Figure 55: Floor plan of atrium-style buildings for the FBD (General Contractor)

There has been no modification regarding the shading design in specific the external shading devices, which have been finalised for the FPPD as described in chapter 3.2.6 with the dimensions of the roof overhang provided in Table 24. But due to the cost-efficiency measure (see also chapter 3.3.5) the solar tubes, which have been considered during the detailed planning permit stage, have been replaced by additional windows in the bathroom and the EH facing NNE. An operable window in the LK facing SSW enables a cross ventilation in the building. Furthermore, the window for the panoramic view of the Atrium East building has been removed. In addition the height of all windows has been reduced from 2.7 m to 2.3 m (see Figure 55 and Figure 56).

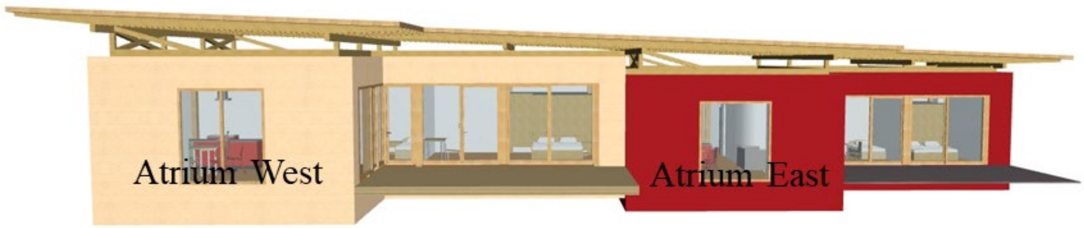

Figure 56: South view of the atrium-style building for the FBD (Arch. Scheicher)

Also the structure of the modular building elements has been modified towards a more economic construction due to standardisation, unification and material reduction measures, but also because of fire protection requirements for the separation wall between the two atrium-style buildings. Leading to a slightly reduced performance of the building envelope compared to the design of the prior stage (exterior walls=0.06 W/m²K; roof=0.07 W/m²K; floor=0.08 W/m²K). The detailed constructions and values are displayed in Table 57, Table 58, Table 59, Table 60 and Table 61 in the appendix. These are then combined with high performance triple glazing wood frame windows from a local producer using the product specific values (Ug = 0.50 W/m²K; Uf = 1.08 W/m²K; g-value = 0.50).

Building Compound

In final design stage also the design of the building compound has been adapted due to the collaboration with the construction companies with the aim to develop ecological, but economical constructions for the prototype buildings.

The size and the GFA of the FPPD remains the same, but there have been some significant amendments for the general layout of the building compound. First of all, the central staircase has been relocated on the outside to allow individual access to the living units on the northern side of the building. With that measure and the decision to downscale the two-storey high gallery of the CA to the GF only, an additional living unit in the UF above the CA could have been integrated in the building compound without expanding the building. Second, the housing technology system has been further centralised. By implication, a room especially for technical installations within the building compound is no longer required.

And last but not least, in contrary to the described static construction in chapter 2.2 with attached prefabricated elements to a wooden skeleton structure, the building is being realised with prefabricated modular boxes for the living units, which are attached to each other. See also Figure 73 in chapter 3.3.5 for an illustration of this building concept for an increased industrial prefabrication. The layout modifications of the building compound are displayed in Figure 57 for the GU and in Figure 58 for the UF.

Figure 57: Floor plan (GF) of the building compound for the FBD (Arch. Scheicher)

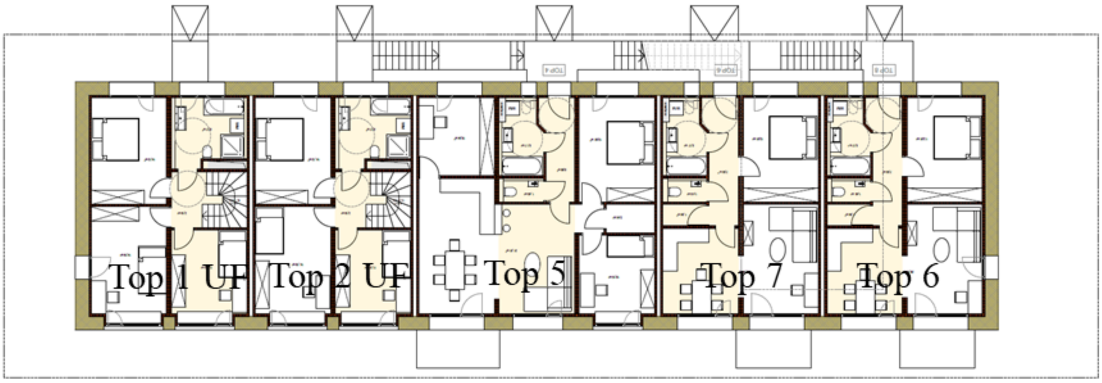

Figure 58: Floor plan (UF) of the building compound for the FBD (Arch. Scheicher)

These modifications of the general building design are in further consequence also leading to amendments for a more unified room layout with a high modularity, while maintaining the origin design. Type and dimensions of the modular boxes have caused further adaptions. For each living unit all housing technology is always integrated in one box containing the wet rooms for short pipe lengths. As a consequence, regarding Top 2 a relocation of the kitchen was necessary, while an additional work space was added in the GF together with a small SR under the staircase. In return the TR in the UF is not needed anymore (see Figure 59). The number of thermal zones for Top 2 is increased from 10 to 11. Regarding the small apartments, the location of the kitchen has been exchanged with the bedroom, while the bathroom is situated at the same wall allowing also an entrance door to the north. Since the WC is now separated from the bathroom, these living units consist of 6 instead of 5 thermal zones. See Figure 60 for the adaption of Top 4 and 6. Furthermore, the design of top 3 is now matching Top 5 due to the removed room for technical installations, achieving a more unified and standardised design. Also adaptive design aspects have been integrated in the concept of all living units. In total, the number of thermal zones for the building compound climbed up to 60.

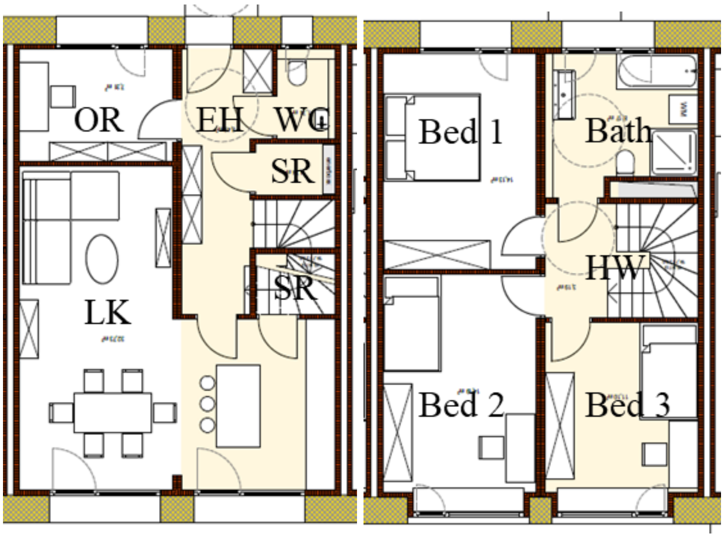

Figure 59: Left: Floor plan Top 2 GF; right: Top 2 UF for the FBD (Arch. Scheicher)

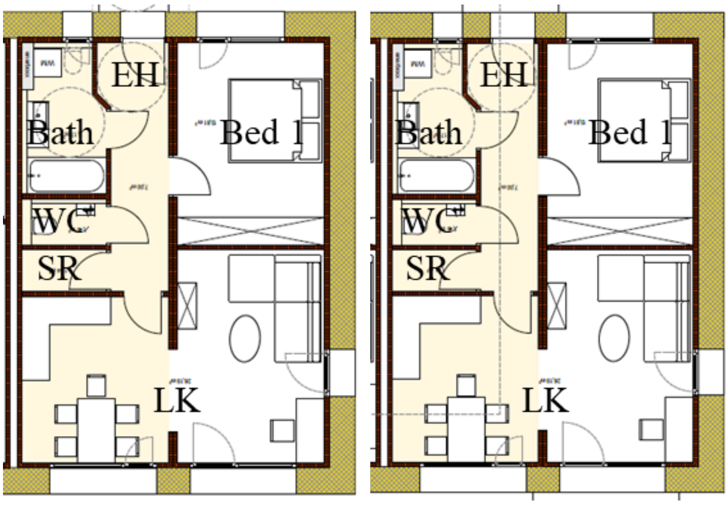

Figure 60: Left: Floor plan Top 4 GF; right: Top 6 UF for the FBD (Arch. Scheicher)

There are no amendments for the design of the extended roof in this stage, but because of the varying room layout and the additional living unit, the size and order of the balconies is divergent to the prior stage (see Figure 61).

Figure 61: South view of the building compound for the FBD (Arch. Scheicher)

The detailed dimensions of the external shading elements for the building compound are provided in the following Table 32. Due to the adjustments also the positions and dimensions of the transparent building elements had to be adapted slightly to match with the grid of the modular boxes and the new room layout (see Figure 57 and Figure 58).

Table 32: Roof and balcony variables for the FBD of the building compound

Variable	**North**	**East**	**South**	**West**
Roof depth [m]	2.0	4.5	2.0	2.8
Balcony depth Top 3 [m]	-	-	1.7	-
Balcony depth Top 4 [m]	-	-	1.7	-
Balcony depth CA [m]	-	-	1.7	-
Balcony length Top 3 [m]	-	-	3.5	-
Balcony length Top 4 [m]	-	-	3.3	-
Balcony length CA [m]	-	-	3.3	-

Due to the change of the general layout with the use of modular boxes, also the building elements have been adapted. The constructions have been simplified, the number of layers and materials reduced. The thickness of the baseplate decreased from 64 to 58 cm, while the thickness of the insulation layer increased from 35 to 48 cm. Consequently, the roof's construction thickness as well as the insulation increased by the same length from 35 to 48 cm, without altering the total height of the building. In addition, instead the initially foreseen straw bales for all constructions blow-in insulation made of straw is used, like for the ceiling and baseplate of the atrium-style buildings (see 3.2.2). Resulting in decreased u-values for all building elements of the thermal envelope (exterior wall=0.09 W/m²K; roof=0.09 W/m²K; floor=0.09 W/m²K) compared to the constructions of the FPPD. The exact materials and precise values of the building compound are displayed in Table 76, Table 77 and Table 78 in the appendix. These constructions are, as for the atrium-style buildings, combined with high performance triple glazing wood frame windows from a local producer using the product specific values (U_g = 0.50 W/m²K; U_f = 1.08 W/m²K; g-value = 0.50).

3.3.3 Results for the final building design

The results of the FBD for the atrium-style buildings and the building compound, as described in the prior chapters 3.3.1 and 3.3.2, are displayed in the following chapter. The total number of hours with indoor temperatures above 26 °C – for the evaluation of the indoor environment for the individual zones and total buildings as well as the heating demands and intensities calculated for EP+ and GEQ – are stated, supplemented with the heating and ventilation scenarios for the selected zones. The assessment of the overheating risk according to the Austrian Standards is provided in the succeeding chapter 3.3.4.

Atrium buildings

The design modifications for the FBD of the atrium-style buildings are also leading to varying results for the indoor temperatures and heating intensities compared to the previous design stages. The main influencing parameters are the positions and sizes of the transparent surfaces, which are effecting the transmitted solar radiation, resulting in differing values for the total numbers of hours with indoor temperatures above 26 °C and for the calculated heating intensities. Table 33 is showing that the numbers of hours with indoor temperatures above 26 °C for the individual zones and for all zones of each atrium-style building together are significantly decreased from 2378 to 1701 h for the Atrium East building and from 2275 to 1682 h for the Atrium west building due to the implemented cost-efficiency measures.

Table 33: Time with indoor temperatures > 26 °C for zones of the FBD of the atrium-style buildings

Building	**Bed1 [h]**	**Bed2 [h]**	**Bed3 [h]**	**SR [h]**	**EH [h]**	**LK [h]**	**WC [h]**	**Bath [h]**	**Zones 1-8 [h]**
Atrium East	1139	1552	1132	696	682	1443	936	561	1701
Atrium West	1124	1532	1092	648	626	1405	917	558	1682

The amendments of the design affect also the total number of hours with indoor temperatures above 26 °C for the adapted HSP. Accordingly, the low FC and the high FC scenarios are decreased, while maintaining similar tendencies. An overview of the results for the different scenarios of the atrium-style buildings for the period of a whole year and the summer period only is provided in the following Table 34.

Table 34: Time with indoor temperatures > 26 °C for scenarios of the FBD of the atrium-style buildings

Building and period	**Standard HSP [h]**	**Adapted HSP [h]**	**Low FC [h]**	**High FC [h]**
Atrium East	1701	1719	701	292
Atrium East summer period	1530	1536	530	121
Atrium West	1682	1696	688	293
Atrium West summer period	1512	1525	518	123

The indoor temperatures for the standard HSP and the adapted HSP scenarios of the Atrium East building are exemplified in more detail for the individual thermal zones in the following Figure 62 and Figure 63.

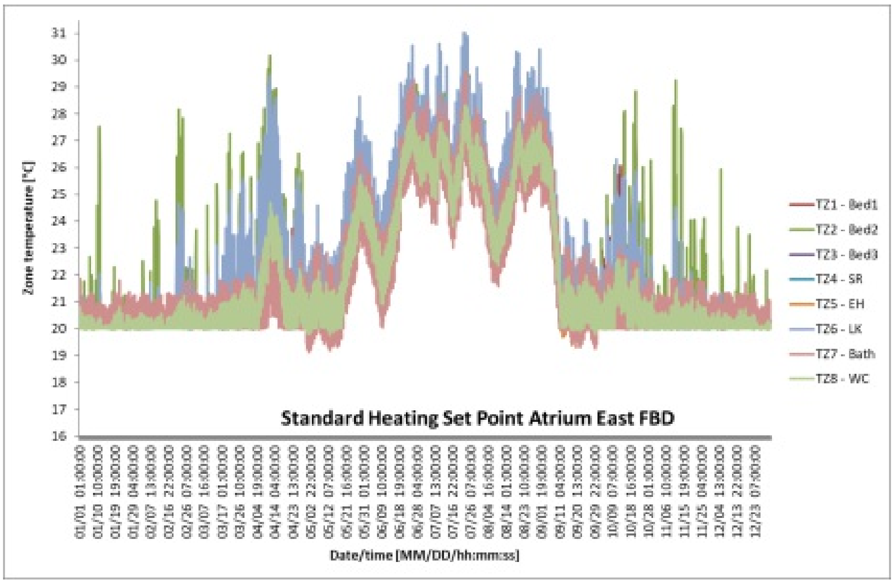

Figure 62: Indoor air temperatures for the standard HSP model of the Atrium East building FBD

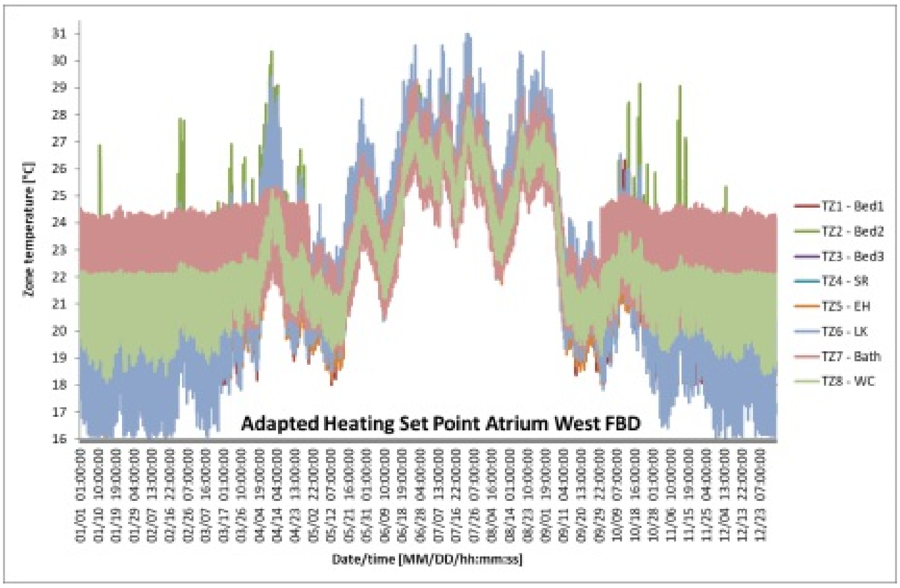

Figure 63: Indoor air temperatures for the adapted HSP model of the Atrium East building FBD

Compared to the standard HSP model the adapted HSP model of the FBD shows wider variations because of more common set point values for the selected thermal zones (see Table 4). But the total number of hours with indoor temperatures above 26 °C would increase only slightly by 6 to 29 h for the atrium-style buildings depending on the period (see also Table 34). The indoor temperatures for the Standard and adapted HSP models for the Atrium West building of the FBD are displayed in Figure 86 and Figure 87 in the appendix.

Same like in the prior stages, a significant reduction of the indoor temperatures in the summer period can also be achieved for the FBD of the atrium-style buildings due to the application of natural ventilation in the standard HSP model.

For the low FC model of the Atrium East building reductions of 58.8 % to 701 h and of 65.4 % to 530 h can be achieved for the timespan of the entire year and the summer period only, while for the Atrium West building a decrease of 59.1 % to 688 h and of 65.7 % to 518 h can be achieved (see Figure 64 and Figure 88 in the appendix).

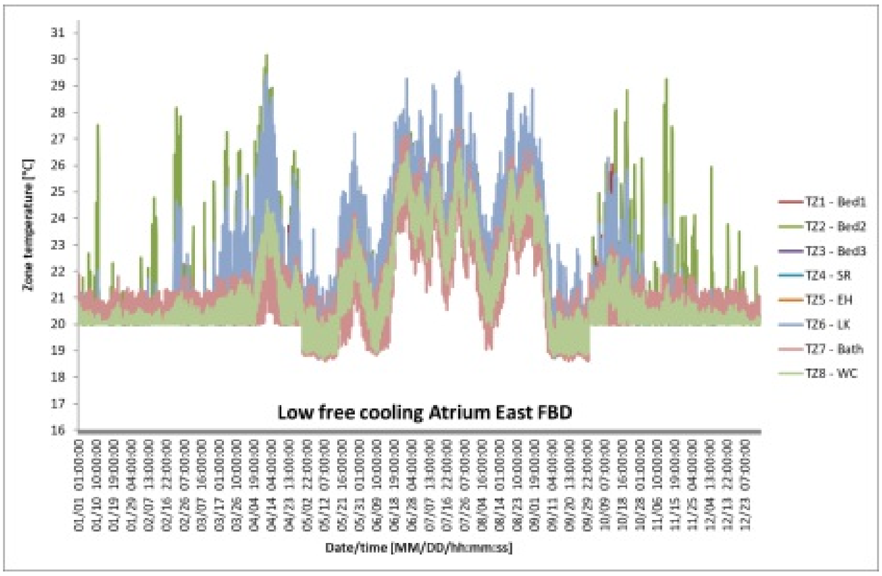

Figure 64: Indoor air temperatures for the low FC model of the Atrium East building FBD

Regarding the high FC model even further decreases are possible due to the application of a higher ACR during the night, resulting in reductions by 82.8 % to 292 h and by 82.6 % to 293 h for the whole timeframe as well as by 92.1 % to 121 h and by 91.9 % to 123 h for the summer period. See Figure 65 for the Atrium East building and Figure 89 in the appendix for the Atrium West building.

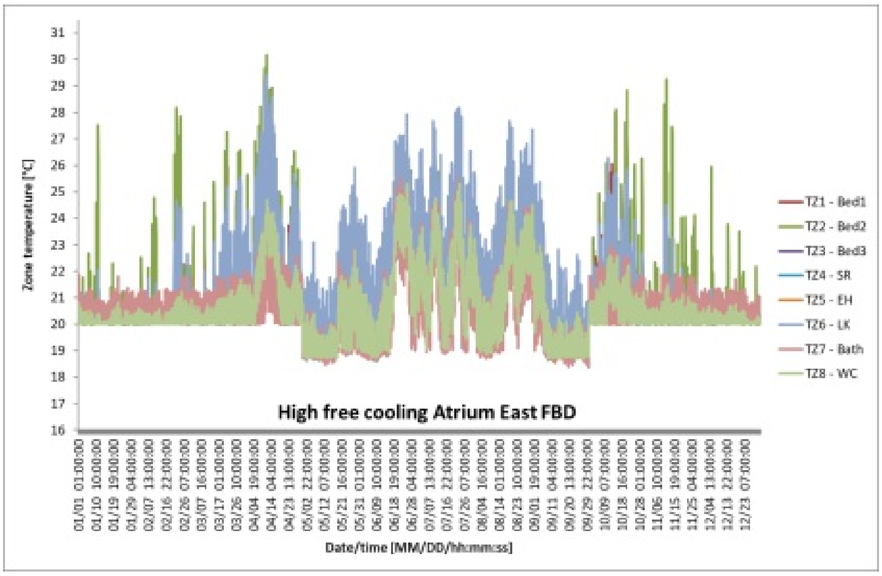

Figure 65: Indoor air temperatures for the high FC model of the Atrium East building FBD

The implemented measures, causing the reduction of the indoor temperatures above 26 °C and contributing to an increased thermal comfort in the buildings, are in return also responsible for the increased values of the calculated heating intensities for the FBD of the atrium-style buildings. The results for the HWB_RK and the HWB_SK of Austrian EPC as well as for the HSP and ventilation scenarios with EP+ are summarized in Table 35.

Table 35: Heating demands of the FBD of the atrium-style buildings

Building	GEQ HWB_RK	GEQ HWB_SK	EP+ Standard HSP	EP+ Adapted HSP	EP+ Low FC	EP+ High FC
Atrium East [kWh/a]	2766	3067	2414.94	3328.89	2423.72	2425.11
Atrium East [kWh/(m²a)]	18.18	20.17	18.12	24.98	18.19	18.20
Atrium West [kWh/a]	2825	3131	2416.31	3350.70	2424.97	2426.23
Atrium West [kWh/(m²a)]	18.57	20.58	18.13	25.14	18.19	18.20

Both atrium-style buildings feature a GFA of 152 m², an A/V of 0.81 1/m and a lc of 1.24 m. The calculated heating intensities are showing values of 18.18 kWh/(m²a) for the HWB_RK and 20.17 kWh/(m²a) for the HWB_SK of the Atrium East building and 18.57 kWh/(m²a) for the HWB_RK and 20.58 kWh/(m²a) for the HWB_SK of the Atrium West building. The heating intensities have been increased by approximately 5 kWh/(m²a) according to the Austrian EPC compared to the results of the FPPD.

This tendency is likewise reflected in the results of the FBD with EP+. The implemented design modifications are resulting in increased values of 18.12 and 18.13 kWh/(m²a) for the standard HSP models, 24.98 and 25.14 kWh/(m²a) for the adapted HSP models, 18.19 kWh/(m²a) for low FC models and 18.20 kWh/(m²a) for the high FC models.

Building Compound

The implemented cost-efficiency measures are also leading to varying results for the FBD of the building compound compared to the FPPD. Amongst other optimisations, the modified construction elements, but also the adapted room layout with partly different intended usage and in consequence deviating internal gains, are resulting in reduced numbers of hours with indoor temperatures above 26 °C and also slightly decreased values for the calculated heating intensities. The numbers of hours with indoor temperatures above 26 °C for the individual zones of the selected Tops 2, 4 and 6 for the standard HSP scenario are provided in the following Table 36. The values for all zones are dropping down from 2756 to 2198 h for Top 2, from 2773 to 2102 h for Top 4 and from 2515 to 2204 h compared with the results of the FPPD.

Table 36: Time with indoor temperatures > 26 °C for zones of the FBD of the compound

Living unit	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	SR2 [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	OR [h]	All [h]
Top 2	1619	1770	1897	406	877	565	1200	1783	862	1308	1226	2198
Top 4	1472	-	-	1252	-	1045	-	1989	1008	1220	-	2102
Top 6	1440	-	-	1339	-	1044	-	2082	1396	1309	-	2204

Corresponding to the results of the standard HSP scenario, also the total number of hours with indoor temperatures above 26 °C for the adapted HSP, the low FC and the high FC scenarios for the period of a whole year and for the summer time from 1st of May until the 30th of September are decreased accordingly with similar tendencies like for the FPPD. An overview of the selected living units and the entire building compound is provided in the Table 37.

Similar to the FPPD, the adpated HSP models show wider temperature variations than the standard HSP models, because of more commen set point values comapred to the low standard assumption of the Austrian EPC. This behaviour, especially for the zones with lower night time temperatures, is exemplified in detail for the individual zones of Top 2 for the standrad HSP model in Figure 66 and for the adapted HSP model in Figure 67.

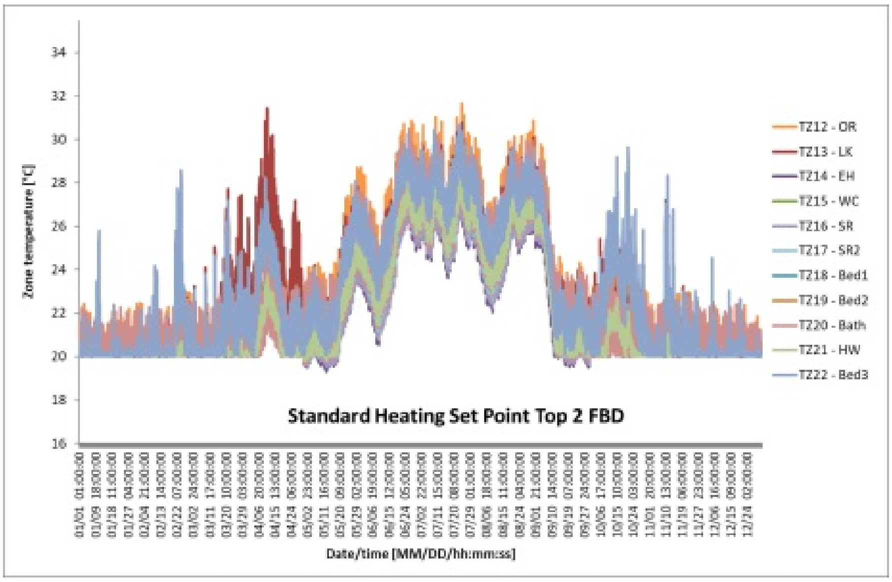

Figure 66: Indoor air temperatures for the standard HSP model of Top 2 FBD

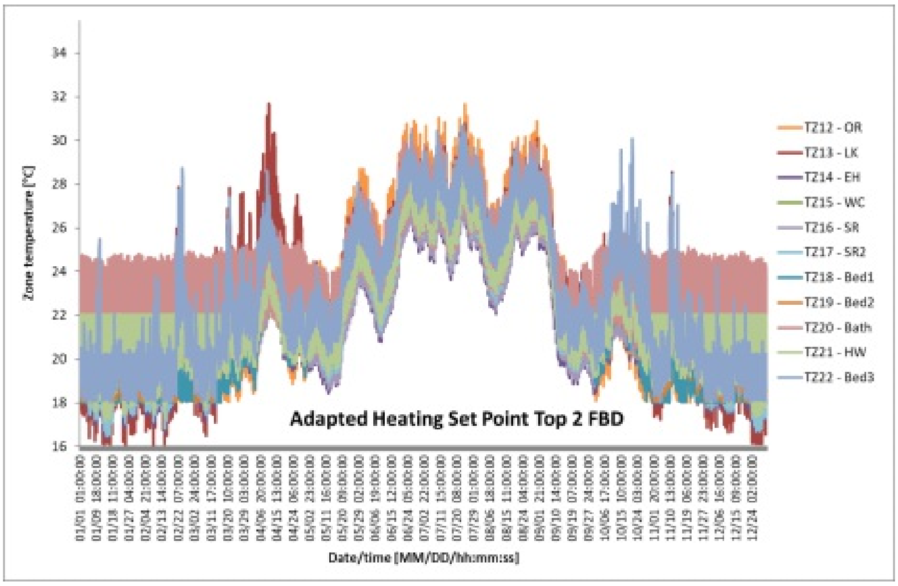

Figure 67: Indoor air temperatures for the adapted HSP model of Top 2 FBD

The scenarios of Top 4 and 6 are displayed in the appendix in Figure 90 and Figure 91 for standard HSP model as well as in Figure 92 and Figure 93 for the adapted HSP model. Depending on the period, the total number of hours with indoor temperatures above 26 °C would increase from 8 to 65 h for the entire building compound (see Table 37).

Table 37: Time with indoor temperatures > 26 °C for scenarios of the FBD of the compound

Hours with temperatures > 26 °C for all zones per living unit	**Standard HSP [h]**	**Adapted HSP [h]**	**Low FC [h]**	**High FC [h]**
Top 2 All year	2198	2265	1099	446
Top 2 summer period	1881	1896	782	129
Top 4 All year	2102	2155	1084	481
Top 4 summer period	1819	1825	801	199
Top 6 All year	2204	2253	1140	536
Top 6 summer period	1858	1864	794	191
Compound	2298	2363	1251	583
Compound summer period	1926	1934	879	212

Likewise the atrium-style buildings and the results of the FPPD stage, also for the FBD of the building compound a significant reduction of the indoor temperatures can be achieved due to the application of natural ventilation in the standard HSP model for the summer period (see Figure 68 for Top 2 as well as Figure 94 and Figure 95 in the appendix for Top 4 and 6). This results in a decrease of 50.0 % to 1099 h for Top 2, by 48.4 % to 1084 h for Top 4 and by 48.3 % to 1140 h for Top 6 for the period of a whole year, while for the summer time reduction of 58.4 % to 782 h, 55.7 % to 801 h and 57.3 % to 794 h can be achieved for Top 2, 4, and 6 (see Table 37).

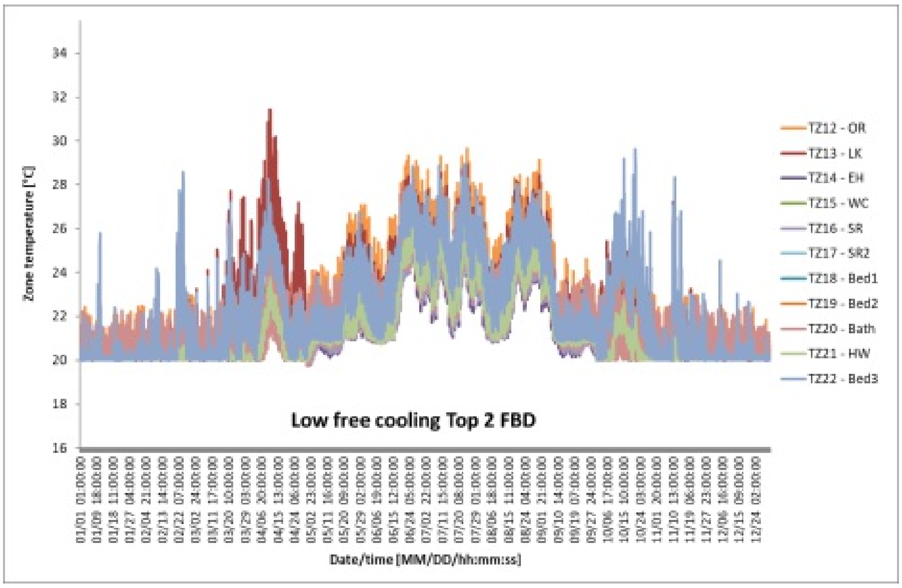

Figure 68: Indoor air temperatures for the low FC model of Top 2 FBD

This tendency is also persisting for the high FC model, which is illustrated in the following Figure 69 for Top 2 as well as in Figure 96 and Figure 97 in the appendix for Top 4 and 6. The increased ACR for a higher night time natural ventilation is leading to further reductions of the indoor temperatures in the living units and in the entire building compound. Resulting in a fall-off by 79.7 % to 446 h for Top 2, by 77.1 % to 481 h for Top 4 and by 75.7 % to 536 h for Top 6 compared to the standard HSP scenario considering the period of a whole year. Comparing the summer period decreases by 93,1 % to 129 h for Top 2, by 89.0 % to 199 h for Top 4 and by 89.7 % to 191 h are possible (see Table 37).

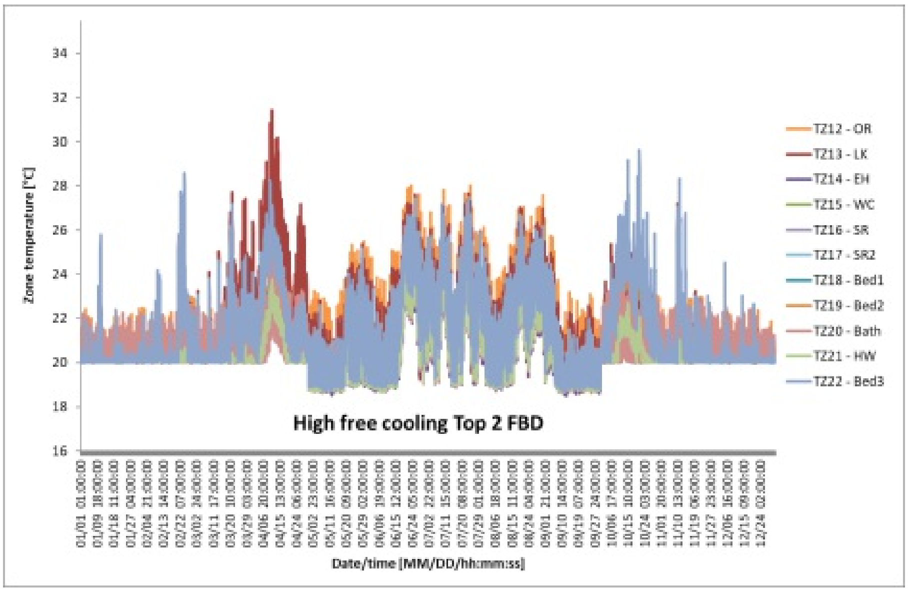

Figure 69: Indoor air temperatures for the high FC model of Top 2 FBD

The implemented measures for the building compound in this design stage are leading to an overall optimised building design with significantly reduced indoor temperatures and decreased heating intensities compared to the FPPD of the prior stage. The results of the building compound for the HWB_RK and the HWB_SK of Austrian EPC as well as for the HSP and ventilation scenarios with EP+ are summarized in the following Table 38.

Table 38: Heating demands of the FBD of the compound

Building	**GEQ HWB_RK**	**GEQ HWB_SK**	**EP+ Standard HSP**	**EP+ Adapted HSP**	**EP+ Low FC**	**EP+ High FC**
Compound [kWh/a]	8496	9686	10082.26	14156.56	10060.70	10142.73
Compound [kWh/(m²a)]	10.88	12.40	13.48	18.93	13.45	13.56

The optimised FBD shows calculated values of 10.88 kWh/(m²a) for the HWB_RK and 12.40 kWh/(m²a) for the HWB_SK with a GFA of 781 m², an A/V of 0.51 1/m and a lc of 1.95 m. This tendency is also reflected in the calculated heating intensities with EP+ for the standard HSP model with 13.48 kWh/(m²a), the adapted HSP model with 18.93 kWh/(m²a), the low FC model with 13.45 kWh/(m²a) and for the high FC model with 13.56 kWh/(m²a).

3.3.4 Assessment of overheating risk final building design

After evaluating the heating intensities and the indoor environment in view of the indoor temperatures, the FBD is examined regarding it's potential for preventing summertime overheating according to the requirements of the Austrian standards (see chapter 2.4.). In a second step, the results are compared with the outcomes of the findings calculated with EP+ like for the evaluation of the building models in the FPPD stage (see chapter 3.2.5).

The assessment is conducted for the FBD of the atrium-style buildings (see Figure 55) as well as for the FBD of the selected living units Top 2, 4 and 6 (see Figure 59 and Figure 60). The results are mirroring the findings of the FPPD stage but with some deviations because of the design optimisation. In any case, additional measures are also necessary for the FBDs, e. g. exterior shades. The relevant thermal zones of these living units, which contain window elements, are displayed in following Table 39 and Table 40. These also contain the window orientation, the building level and the minimum required operation times of exterior shades for approval of the Austrian standard.

Table 39: Minimum required approval settings for prevention of overheating for FBD Atrium buildings

Building	**Atrium East**												
TZ	Bed1		Bed2		Bed3	LK					EH		Bath
Window	S1	S2	S1	S2	S1	E1	E2	E3	S1	S2	N1	N2	N1
Orien.	SSW	SSW	SSW	SSW	SSW	ESE	ESE	ESE	SSW	SSW	NEN	NEN	NEN
Ext. shades [time]	-	14-15	-	-	-	-	-	-	13-17	13-17	-	-	-
Building	**Atrium West**												
TZ	Bed1		Bed2		Bed3	LK					EH		Bath
Window	S1	S2	S1	S2	S1	E1	E2	E3	S1	S2	N1	N2	N1
Orien.	SSW	SSW	SSW	SSW	SSW	ESE	ESE	ESE	SSW	SSW	NEN	NEN	NEN
Ext. shades [time]	-	14-15	-	-	-	-	-	-	14-16	14-16	-	-	-

The results for the atrium-style buildings show that, due to the amendments the minimum required operation time of the exterior shades is in general slightly reduced. Especial the removal of the east oriented window element in case of the Atrium East building is leading to significant decreased operation times for the thermal zones Bed1 and Bed2. The supplemented window elements in the EH and in the Bath, which are replacing the initial foreseen solar tubes, do not require any additional measures.

Table 40: Minimum required approval settings for prevention of overheating for the FBD of the building compound

Building	**Compound Top 2**														
TZ	LK				OR		WC	Bed1		Bed2		Bed3		Bath	
Floor	GF	GF	GF	GF	GF	GF	GF	UF	UF	UF	UF	UF	UF	UF	UF
Window	S5	S6	S7	S8	N4	N5	N6	N5	N6	S5	S6	S7	S8	N7	N8
Orien.	S	S	S	S	N	N	N	N	N	S	S	S	S	N	N
Ext. shades [time]	12-15	12-15	12-15	12-15	-	-	-	-	-	12-14	12-14	12-15	12-15	-	-
Building	**Compound Top 4**														
TZ	LK					Bed		Bath							
Floor	GF	GF	GF	GF	GF	GF	GF	EG							
Window	E1	S19	S20	S21	S22	N16	N17	N15							
Orien.	E	S	S	S	S	N	N	N							
Ext. shades [time]	-	10-15	10-15	10-15	10-15	-	-	-							
Building	**Compound Top 6**														
TZ	LK					Bed		Bath							
Floor	UF	UF	UF	UF	UF	UF	UF	UF							
Window	E1	S19	S20	S21	S22	N18	N19	N17							
Orien.	E	S	S	S	S	N	N	N							
Ext. shades [time]	-	10-17	10-17	10-17	10-17	-	-	-							

The findings for the building compound also show similar results with some deviations due to the amendments. Based on the modified room size and geometry of the LK, as well as in general reduced transparent surfaces, a reduction of the required window shade operation time could be achieved for Top 2. For the additional OR situated at the north façade no additional measures are needed. The operation times for the bedrooms show similar but slightly reduced values compared to the FPPD, but because of the location exchange of Bed1 and Bed3 with reversed times for these thermal zones. For the FBD of Top 4 additional measures are only required for the LK. This thermal zone is because of the modified room layout now completely situated along the south façade and therefore suspended to a higher degree of solar radiation compared to the FPPD. Nonetheless, due to the reduced number of window elements and less transmitted solar radiation through the transparent surfaces, the operation time of the exterior shades is in return decreased slightly. Top 6 shows similar results as Top 4 because of the same adaptions. An exterior shading is needed for all south oriented windows of the LK, but none for the bedroom, which is now located in the NW corner of the living unit and building.

In the next step, the required operational time of the exterior shades are applied to the building model in EP+ like in the FPPD stage with the same ventilation parameter according to the Austrian standards (see chapter 2.4) and compared to the findings of the Austrian EPC. The results for Top 2 are illustrated in Figure 70 and Figure 71 below, while the indoor temperatures for Top 4 and 6 are displayed in the appendix (see Figure 106, Figure 107, Figure 108 and Figure 109) as well as the ones for the atrium-style buildings (see Figure 110, Figure 111, Figure 112 and Figure 113).

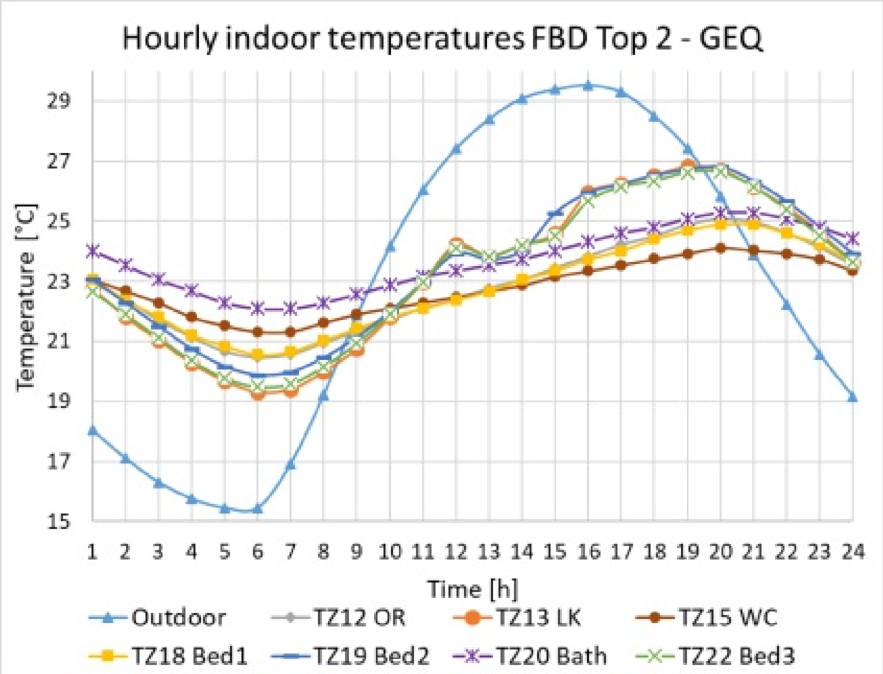

Figure 70: Indoor temperatures of FBD Top 2 for GEQ

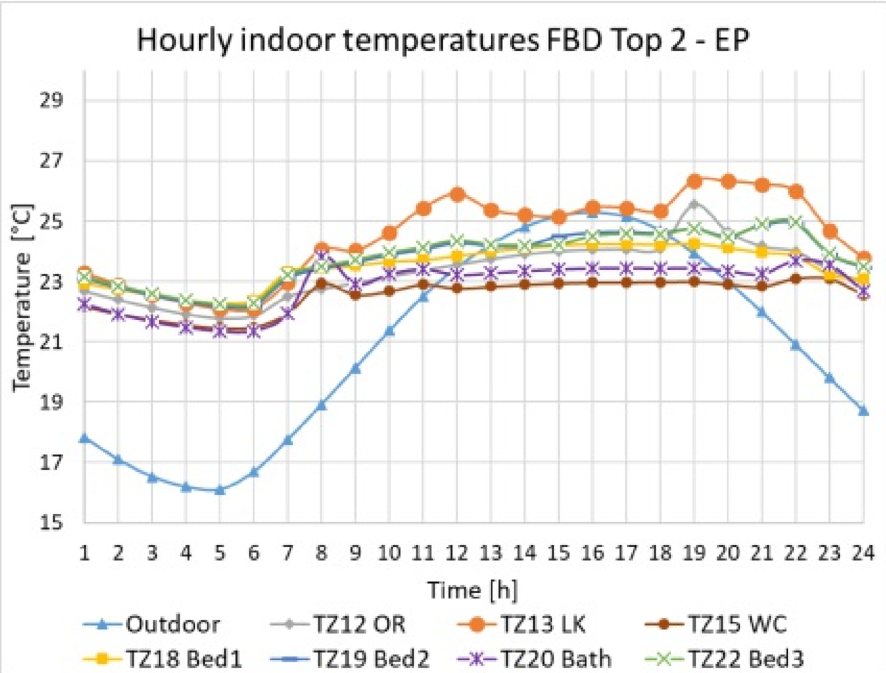

Figure 71: Indoor temperatures of FBD Top 2 for EP+

All computed results show similar tendencies to the findings of the FPPD. Thermal zones with large and south oriented building openings show a wider temperature variation between day and night than those with small and north oriented openings. The same applies for the results of the different software. Due to the bigger temperature spread of the outdoor temperature for GEQ also the indoor temperatures show larger differences than the building model in EP+, which is in contrary showing more constant values throughout the day. The amendments of the building design, e. g. the exchanged location of the bedrooms for Top 2, are reflected in the graphs.

Likewise the building compound, also the indoor temperatures of the atrium-style buildings of the FBD are in average almost on the same temperature level. The in average higher temperature difference between the results for GEQ and EP+ in the FPPD stage for the atrium-style buildings, which was also reflecting the observed effects derived by the deviations of the varying solar radiations (see chapter 3.2.4), has been minimised. This effect is also caused by the reduction of the transparent surfaces facing south and the increased amount of window elements, which are not facing to any cardinal direction between SSW and SSE.

3.3.5 Workflow final building design stage

Proceeding from the prior stage's results, the starting point for this stage is the finalised building design for the atrium-style buildings and the building compound of the detailed planning permit stage as displayed in Figure 5 of the overall optimisation process.

The entire project team including the project management team, the external experts as well as the different construction companies under the lead of the general contractor are conducting the optimisation of the prototype building in this final building design stage. In the next step, the optimisation of the buildings towards the FBD for the production of the building elements and construction of the prototype buildings is being realised in an integral planning approach with additional support from a building inspector to guarantee a complete planning record of high quality. The system boundaries for the planning workflow in the final building design stage are displayed in the following Figure 72.

In contrary to the prior design stages, the building optimisation was not performed in a linear or circular approach, but based on heuristic verification of suggested cost-efficiency measures as described in chapter 2.3.3., implemented in the FBD.

Lines of communication between the involved stakeholders were, as in the prior stages, emails, phone conferences or meetings. Furthermore, with the start of the production of the building elements and especially the construction on site, the information exchange's frequency rose. It is no longer taking place on demand only, but also in subject-oriented site consultation meetings on a weekly base and under the supervision of the building inspector.

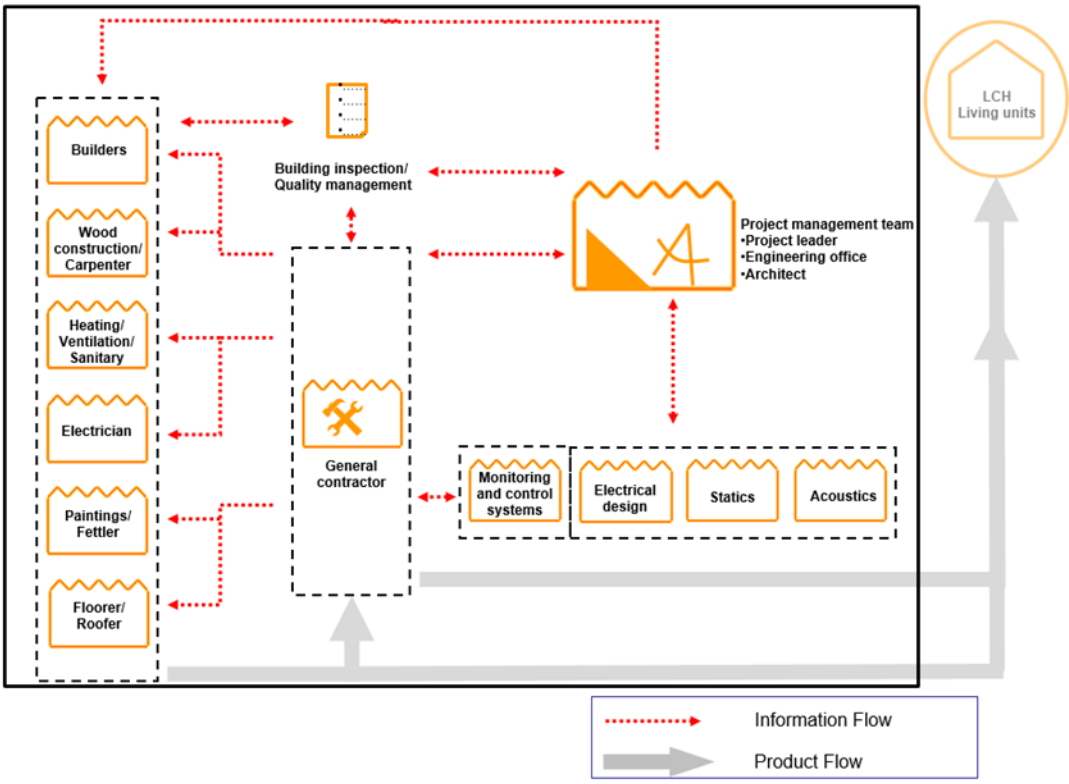

Figure 72: Workflow of the final design stage

Based on their manufacturing experience, the construction companies under the lead of the general contractor have been especially encouraged to contribute ideas for an economic optimisation of the prototype buildings. The building design optimisation suggestions have been verified and accepted by the project leader, depending on the compatibility with the overall project objectives and above all regarding the ecological and energy-efficiency targets.

Focal points of this process encompass three major areas. First, by minimising individual design solutions towards a simplification, unification and standardisation of the constructions, e. g. by reducing the number of material layers and the quantity of different building elements, and by avoiding custom-made products like the initially envisaged windows for the atrium-style buildings covering the full ceiling height. Second, by lowering the human resources costs, especially regarding the time consuming volume of work occurring on the construction site. Third, by increasing the number of living units without expanding the building size in order to achieve a higher economic output afterwards.

Subsequently, the accepted suggestions were leading to a modified building design with a high degree of prefabrication especially for the building compound using transportable modular boxes for the core construction (see Figure 73).

Figure 73: Building concept with prefabricated modular boxes (Arch. Scheicher)

3.4 Ecological evaluation

The ecological evaluation for the prototype buildings is conducted due to the comparison of ecological indicators as stated in chapter 2.5 for the final building designs of the three major planning stages. Therefore, starting with the values extracted from the database for the PEI [MJ/kg], the GWP [kg CO2 equi./kg] and the AP [kg SO2 equi./kg] the values for each material used in the varying building elements for 1 m² of the construction are calculated. The detailed values for the PEI [MJ/m²], the GWP [kg CO2 equi./m²] and the AP [kg SO2 equi./m²] are provided in the appendix in Table 90 to Table 97 for the final building designs of the early design stage, in Table 99 to Table 107 for the FPPD and in Table 109 to Table 117 for the FBD.

Furthermore, the values of PEI, GWP and AP are added up for the used m² of each construction and for the entire buildings. The results for the constructions of the FBD for all building types are displayed in the following Table 41. The results for the constructions of the final building models of the early design stage and for the FPPD are shown in detail in Table 98 and Table 108 in the appendix.

Table 41: Ecological indicators constructions FBD

Atrium-style buildings	**Surface [m²]**	**PEI [MJ]**	**GWP [kg CO_2]**	**AP [kg SO_2]**
Exterior wall	132.5	70253.3	-18641.3	26.2
Exterior wall clay	29.8	14055.0	-3922.1	5.3
Floor construction	152.1	109822.8	-22059.2	39.5
Roof construction	152.1	104399.8	-29805.5	36.8
Separation wall	28.0	11913.9	-3630.1	5.0
Windows/doors	35.3	27330.2	852.0	11.8
Total		337775	-77206	125
Compound				
Exterior wall	538.7	328149.6	-90990.0	122.8
Floor construction	404.5	281831.9	-50950.9	99.3
Roof construction	404.5	380135.4	-80941.4	119.4
Interior ceiling	376.6	428552.7	-45413.8	129.5
Windows/doors	169.5	139882.3	3037.8	56.2
Total		1558552	-265258	527

The total results for the ecological indicators comprising the values of all constructions for the building types in the different planning phases are summarised in Table 42. The calculated results for the entire buildings are varying during the optimisation process. Based on the intended building designs with the basic simplified constructions and maximum use of ecological building materials, the PEI values are increasing for the FPPD during the optimisation process in the detailed planning stage due to resource intensive constructions. The GWP is ditto further increasing in the negative scale. Due to the modifications for the FBD of the atrium-style buildings this effect in partly reversed, while the ones for the building compound are leading to a further increased PEI, but also to a reduced GWP in the negative scale.

Table 42: Development of total ecological indicators

Atrium East	**PEI [MJ]**	**GWP [kg CO_2]**	**AP [kg SO_2]**
Early design stage	362795	-73430	128
FPPD	392574	-93742	128
FBD	337775	-77206	125
Atrium West			
Early design stage	362754	-73410	128
FPPD	389361	-94111	127
FBD	337775	-77206	125
Compound			
Early design stage	1164448	-183112	344
FPPD	1424160	-284846	418
FBD	1558552	-265258	527

Major impacts on the varying ecological indicators, in addition to the ones caused by the performance optimisation, are owing to the requirements according to the Austrian standards and to cost optimisation measures.

For example, the acoustical requirements between the apartments in the building compound situated on top of each other have not been considered in the intended design and were insufficient. Likewise, additional fire protection measures between the living units in the building compound had to be integrated. Furthermore, the use of the prefabricated Variotherm heating system instead of a floor construction with hemp and clay, as well as a simplified roof construction with ECB instead of green roofs are mainly influencing the ecological indicators as well as the number and size of the transparent building elements.

3.5 Application to different climate locations in Austria

Four cities representing each different climate regions of Austria have been selected in order to investigate the suitability of the developed building concepts for replication in other locations in Austria. The chosen cities are: Vienna, Innsbruck, Klagenfurt and Mallnitz (Bointner, et al., 2012).

Table 43: Climate locations in Austria

Location	Latitude [°]	Longitude [°]	Sea level [m]	Climate region characteristic
Vienna	48.20	16.37	198	Eastern parts of Austria
Innsbruck	47.26	11.40	577	Valley in alpine mountains in western parts of Austria
Klagenfurt	46.63	14.31	447	Locations with cold climate conditions in winter
Mallnitz	46.98	13.16	1185	Alpine mountains with atmospheric inversion in winter, especially at the southern side of the alps

With a distance of approximately 45 km from the project site to the city centre of Vienna, the climate conditions of Vienna are similar to the ones of Böheimkirchen. The average monthly values for the outdoor temperatures for both are the entire year above the temperature's scale freezing point, while the average maximum of around 21 °C is reached in July. The average annual outdoor temperature is with 10.8 °C similar, while the average annual global radiation of Böheimkirchen is with 134 compared to 132 W/m² of Vienna slightly higher. Especially in the second part of the summer the outdoor temperatures in Vienna are above the ones in Böheimkirchen. This difference is also reflected in the simulated results of the building compound for the total hours of indoor temperatures above 26 °C (see Table 44) with 2445 compared to 2298 h.

Table 44: Indoor temperatures of the building compound for the selected locations

Hours with temperatures > 26 °C for building compound	**Standard HSP [h]**	**Adapted HSP [h]**	**Low FC [h]**	**High FC [h]**
Böheimkirchen	2298	2363	1251	583
Vienna	2445	2540	1447	651
Innsbruck	1452	1540	657	510
Klagenfurt	1911	1959	761	419
Mallnitz	516	575	483	472

Innsbruck's outdoor temperature of 10.1 °C and its global radiation of 135 W/m² are showing almost similar values as Böheimkirchen. But comparing the course during the year, the global radiation in Innsbruck shows in summertime lower and in wintertime higher values, resulting in a reduced overheating risk during the warm season and in a reduced heating demand for the cold season (see Table 45).

Klagenfurt reaches with -3.5 °C in January the lowest monthly average temperature of the selected locations. The annual average temperature lies at 8.7 °C. The summer temperatures on the other side are similar like the ones for Innsbruck, while global radiation values throughout the year are higher resulting in an annual average of 143 W/m².

Mallnitz in contrary has, despite higher outdoor temperatures in wintertime than Klagenfurt, only an annual average temperature of 6.1 °C. Also the global radiation is with 121 W/m² comparable low considering that it is located 1185 m above sea level. This is resulting in a low overheating risk for the developed building concept of the building compound.

The calculated heating intensities of the different software and scenarios for the building compound are summarized in the following Table 45. The results for the heating intensities and overheating risk of the atrium-style buildings are displayed in Table 118, Table 119, Table 120 and Table 121 in the appendix. The results are showing the same deviating tendencies caused by the varying climate conditions. Furthermore, they are reflecting the deviations caused by the effects of the different shading elements (see chapter 3.2.4), which are partly enhanced for individual locations with increased numbers of the heating degree days according to the calculation method of the Austrian EPC.

Table 45: Heating demands of the building compound for the selected locations

Heating intensities [kWh/(m²a)]	**GEQ HWB_RK**	**GEQ HWB_SK**	**EP+ Standard HSP**	**EP+ Adapted HSP**	**EP+ Low FC**	**EP+ High FC**
Böheimkirchen	10.88	12.40	13.48	18.93	13.45	13.56
Vienna	10.88	11.96	12.99	18.36	12.95	13.07
Innsbruck	10.88	12.26	10.57	15.57	10.53	10.63
Klagenfurt	10.88	11.58	13.11	18.35	13.08	13.18
Mallnitz	10.88	11.28	12.16	17.10	12.10	12.20

4 DISCUSSION

The results of this work reveal that the integration of dynamic simulations in the design process of buildings can lead to an optimisation of the desired technical, ecological or economic aspects. By summarizing the in chapter 3 stated findings, the discussion will concentrate on the seven basic elements of the project's optimisation aspects.

<u>Optimisation method and design process</u>

Since a variety of methods to improve a building by use of dynamic simulations exist, not one single strategy, but a number of possibilities, can be chosen. The most suitable method has to be selected according to the development status of the building model and the optimisation parameters effecting the desired PI. Therefore, the selected method can vary during the process. At the beginning of the design process a rapid optimisation approach with the available simplified building model is useful to identify and optimise major obstacles of the preliminary design for an energy-efficient performance of the building. For the completion of the building concept thus a more detailed evaluation and optimisation as well as a verification of the building model using product specific construction data of the final design is recommended. Subsequently, a subdivision into the three major phases along the design process, the early design stage, the final planning permit design stage and the final building design stage, is reasonable (see Figure 5).

This project's focus was clearly put on the architectural design parameters like the building geometry, the opaque and transparent surfaces as well as the shading design. Accordingly, methods like window-to-wall-ratio or a more detailed single PI optimisation also in combination with GenOpt were applied in the early design stage. For the advanced building concept with two key PIs, which are acting in opposing directions, a parametric simulation is more appropriate. These methods can be applied in a linear approach if sufficient, but also in a circular approach for each stage if required. In sum, the results show a continuous optimisation process of the buildings overall design.

<u>Heating demand</u>

The applied methods are leading to suggested energy-efficient building designs from the initial preliminary design to the final building model in each stage with decreased heating intensities fulfilling the envisaged threshold values of 15 kWh/(m²a) for the HWB_RK of the atrium-style buildings and of 10 kWh/(m²a) for the HWB_RK of the building compound according to the Austrian EPC.

In this planning approach also the project partners were given the option to select preferred design solutions in order not to restrict the personal design flexibility, especially for the architectural design (see also chapter 3.2.8), not all suggested building parameters have been implemented in the revised building designs. This resulted in values of 13.11 and 13.23 kWh/(m²a) for the HWB_RK of the atrium-style buildings (see Table 28) and of 11.05 kWh/(m²a) for the HWB_RK of the building compound (see Table 31) for the FPPD stage according to the Austrian EPC.

The calculated heating intensities for the FBD are showing again varying numbers. These are caused primarily by the required cost-efficiency measures covering alternative products and less expensive components, but also by a further unification of the building elements and simplification for the manufacturing process in addition to adaptions of the architectural design (see also 3.3.5). The implemented measures are leading to calculated heating intensities of 18.18 and 18.57 kWh/(m²a) for the HWB_RK of the atrium-style buildings (see Table 35). These have increased by approximately 5 kWh/(m²a) compared to the prior stage and are exceeding the initial threshold value, caused mainly by the reduced south-facing transparent surfaces and additional north-facing window elements. The optimised FBD of the building compound shows a calculated value of 10.88 kWh/(m²a) for the HWB_RK, which is despite the necessary cost optimisation below the one of the FPPD (see Table 38). The reduced solar gains, caused by the smaller windows are compensated by the increased thermal properties of the building elements and by higher internal gains for the same GFA due to the extension of the living units within the building. Resulting in calculated heating intensities in a desired cost-performance ratio, considering the required cost optimisation measures and reduced construction costs, even if the findings are still above the initial threshold values.

Interesting in this context is also the effect of the shading elements on the heating demand deviations (see chapter 3.2.4). Comparing the results of the building model in EP+ with the findings of the Austrian EPC (see Table 21), the heating demands show considerable differences caused by calculation methods and sources of climate data of each software. Nevertheless, the general tendency of the deviations is similar. This applies for the investigated external shading devices apart from effects attributable to south-oriented transparent surfaces of non-rectangular buildings or other objects causing a lateral shading. In these cases, a divergent transmitted solar radiation results in varying calculated heating demands, which has to be considered when applying the proposed optimisation approach.

Thermal comfort

The second key PI, in addition to the heating intensities of the buildings, is the optimisation of the thermal comfort of the occupants due to the temperatures of the indoor environments. This has been target from the FPPD stage, when the principal decision was made not to have any air conditioning systems in the buildings. For each design status and building type, building models with the lowest total number of hours of all thermal zones with indoor temperatures above 26 °C of all simulated variants have been suggested complying the target values for the heating demands. For the initial optimised models of the FPPD values of 1901 h and 1851 h, out of a maximum with 2227 h for the atrium style building (see Table 10), and 2586 h, out of a maximum with 2634 h for the building compound (see Table 19) have been calculated. The selected and implemented design parameters were influencing not only the heating intensities, but also the indoor temperatures are affected. The values are varying during the design and optimisation process in an either more or less conversely relation to the heating demands, resulting in decreased numbers of hours for the standard HSP scenario for the FBD of 1701 h and 1682 h for the atrium-style buildings (see Table 34) as well as of 2298 h for the building compound (see Table 37).

In addition, continuously during the entire optimisation process, the results show a significant reduction of overheating risk during summer time caused specifically by deployment of night-time natural ventilation. Reductions of 45 to 59 % for the low FC scenario for the building types of the FBD compared to the standard HSP building models can be achieved. For the high FC scenario even reductions of 74 to 82 % could be achieved for the different building types. Thus, due to the higher ACR for the natural ventilation, the risk for overcooling the building at night exists in return.

Furthermore, the results clearly show that the requirements regarding prevention of overheating in summer according to the Austrian standards can be fulfilled for these ecological lightweight constructions, when taking into account an accurate design of external fixed shading elements, in combination with exterior mechanical shades, and proper use of windows for passive cooling (see chapter 3.3.4). As shown, there are some differences regarding the minimum requirements for prevention of summerly overheating like in case of the east-oriented thermal zones of the building compound in the FPPD stage. While the roof overhang mainly shades the windows in the UF, the operation of the external window shades in the GF is required to fulfil the standards (see Table 22). For avoiding maintenance intensive dynamic shading devices and for increasing the thermal comfort of the occupants in the GF, the extension of external fixed shading devices e.g. by using balconies all-around should be considered.

Transferability of the building design

The application of the building concepts to locations, which are representing different climate regions occurring in Austria (Vienna, Innsbruck, Klagenfurt and Mallnitz in specific), shows that the developed designs are suitable for replication in other locations than Böheimkirchen. Depending on the different climate conditions the HWB_SK is varying between 11.28 to 12.40 kWh/(m²a) for the building compound and between 19.53 and 23.30 kWh/(m²a) for the atrium-style buildings (see chapter 3.5). Minor adaptions regarding the external fixed shading elements and the area of the transparent surface might lead to an increased performance of the building design for each location.

Ecological building design

The conducted ecological assessment (see chapter 2.5) according to the three most common ecological indicators show, that the development of an energy-efficient and cost-efficient building concept can be aligned also with an environment-friendly concept. Due to the extensive and continuous use of ecological and renewable building materials, the three buildings altogether result in total values of 2234102 MJ for the PEI, of -419670 kg CO_2 for the GWP and of 777 kg SO_2 for the AP (see also Table 41).

Furthermore, most of the constructions consist of renewable resources, which can be separated into the single materials and reused or recycled after the usage phase of the buildings, because of mechanical connections. Exception are for example the separation layer between the living units in the building compound, because of fire protection regulations, or the roof cover, which is not detachable. Alternative ecological but cost-intensive solutions for these are available and have been considered but not selected for the FBD in order not to exceed the pre-defined construction costs (see also chapter 3.4).

Cost-efficient constructions

An economic optimisation had to be integrated in the design process, since the project`s objective is to develop not only ecological and energy-efficient building concepts but also cost-efficient constructions realised with a pre-defined budget and suitable for later replication. The cost optimisation can be divided into three categories as described in chapter 3.3.5. These are first, to optimise the building elements towards simplification, unification and standardisation. Second to increase the degree of the prefabrication and to lower the human resources on the construction site. Third, to optimise the overall layout of the buildings in order to achieve a higher economic output afterwards. This had been a challenging procedure since the rather simple and more easily applicable suggested cost-optimisation measures are mainly resulting in increased heating intensities and a reduced ecological completion of the buildings. The implementation of the threefold cost optimisation are as well reflected in the simulation results. In the end, not only an energy-efficient and ecological but also an economic building design, especially for the building compound (see Figure 73), suitable for replication has been developed.

<u>Planning procedure, cooperation network and workflow</u>

The overall cooperation network of this project as presented in Figure 4 can be divided in three scenarios with varying system boundaries for the three major planning stages, as described in detail in the respective subchapters. In accordance with the extension of involved stakeholders and constellation of the project team the workflow for achieving the project goals is varying.

In the early design stage for developing and optimising the preliminary design of the buildings within the project management team only, the conducted workflow is effective and recommended (see chapter 3.1.4).

In the later stages, multiple calculated suitable building models by use of parametric simulations, led to a large variety of individual design parameters. This agony of choice had pros and cons either way. On the one side innovative aspects and ideas of individual experts are supported. On the other side the danger of missing the initial target values is imminent (see chapter 3.2.8).

Overall, the working procedure for the development of these prototype buildings was sufficient. There is thus optimisation potential especially regarding the integration of construction companies and/or a general contractor for an optimisation of the construction costs (see chapter 3.3.5). These partners should be involved already from the beginning or at least during the development of the FPPD for an integral planning approach for avoiding redundant time consuming work. A conventional procedure with first the development of a functional concept and with the tendering afterwards is not recommended for innovative projects, as this is resulting in increased effort for the general planning. Additional planning rounds and sessions afterwards to modify a finalised building concepts because of exceeding constructions cost should be avoided.

5 CONCLUSION

The overall purpose of this study was to explore if the heating demand and overheating risk according to the Austrian standards of life-cycle oriented buildings can be reduced in the cold and warm seasons respectively due to the pursuit of a simulation-supported optimisation strategy together with an improvement of the planning processes themselves.

The study reveals that the applied strategy can lead to improved results for the heating intensities of the buildings, a reduced overheating risk and increased thermal comfort of the occupants as well as to an ecological and economic optimisation depending on the choice of parameters.

In the early design stage there is in general not enough information available for performing a detailed simulation of the whole building suitable for a comparison with the concurrently executed Austrian EPC. Nonetheless, simplified models, which are getting more precise during the process, can be used to show a tendency for improving the results towards an energy-efficient building.

The results of the detailed optimisation stage show that an accurate design of the building openings and shading elements can reduce the indoor air temperatures while maintaining a low heating demand. Nevertheless, it has to be considered that there are deviations between the software regarding the transmitted solar radiations and therefore also for the heating demands depending on the type of shading element – especially for non-rectangular buildings.

Furthermore, the overheating risk during summer time could be reduced significantly by a proper operation of the windows for passive cooling.

Outlook

After the construction of these prototype buildings, a comprehensive building monitoring will be conducted during the initial occupancy phase to validate the simulated results.

Future research efforts should also involve the reapplication of the building optimisation procedure for varying building types and locations in Austria. In addition to the development of ecological and energy-efficient building concepts in different climate zones with divergent locally available and renewable building materials is envisaged.

Furthermore, the integration of a genetic algorithm for the multi-objective optimisation in the detailed building design stage might improve the applied optimisation strategy and should be further investigated.

INDEX

Abbreviations

Acronym	Meaning
ACR	Air change rate
AP	Acidification potential
A/V	Surface-area to volume ratio
Bath	Bathroom
Bed1,2,3	Bedroom
CA	Community area
CO_2	Carbon dioxide
Cfb	Warm tempered humid climate
EH	Entrance hall
EPC	Energy performance certificate
EPBD	European Performance of Buildings Directive
EP+	EnergyPlus
EU	European Union
FBD	Final building design
FC	Free cooling
FPPD	Final planning permit design
GF	Ground floor
GFA	Gross floor area
GWP	Global warming potential
HSP	Heating set point
HW	Hallway
HWB_RK	Reference climate heating demand
HWB_SK	Location climate heating demand
IGDB	International glass data base
K	Kelvin
LCH	Life Cycle Habitation
LK	Living-kitchen area
nZEB	Nearly zero energy buildings
OIB	Austrian Institute of Construction Engineering
PEI	Primary energy input
PI	Performance indicator
Sim4DLG	Simulationsunterstützte Designoptimierung Lebenszyklus orientierter Gebäude
SME	Small and medium enterprises
SR	Storage room
TR	Room for technical installations
TZ	Thermal Zone
UF	Upper floor
WC	Cloakroom
WWR	Window-to-wall ratio

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APPENDIX

A. Tables

Atrium building elements early design stage

Table 46: Exterior wall atrum-style buildings early design stage

AW01 Außenwand				
	von Innen nach Außen	Dicke	λ	d / λ
Lehmputz		0.0300	0.810	0.037
Baustrohballen		0.8000	0.049	16.327
Kalkputz/Voranspritzer		0.0300	0.570	0.053
Kalkputz		0.0100	0.830	0.012
	Rse+Rsi = 0.17	Dicke gesamt 0.8700	U-Wert	0.06

Table 47: Roof construction atrium-style buildings early design stage

DD01	Außendecke, Wärmestrom nach unten						
			von Innen nach Außen		Dicke	λ	d / λ
Holzboden, Vollholz					0.0100	0.160	0.063
Lehmestrich			F		0.0800	0.160	0.500
Schüttungen aus Sand, Kies, Splitt (1800 kg/m^3)					0.0800	0.700	0.114
Nutzholz (425 kg/m^3) - rauh, luftgetrocknet					0.0240	0.110	0.218
Nutzholz (425 kg/m^3) - gehobelt, techn. getrocknet dazw.				8.7 %	0.7000	0.110	0.553
Baustrohballen				91.3 %		0.050	12.783
Brettschichtholz verleimt aussen (475kg/m^3 -Fi/Ta)					0.0940	0.120	0.783
	RTo 14.7050	RTu 14.5655	RT 14.6352		Dicke gesamt 0.9880	U-Wert	0.07
Nutzholz (425 kg/m^3) -	Achsabstand	0.460 Breite	0.040		Rse+Rsi	0.21	

Table 48: Floor construction atrium-style buildings early design stage

FD01	Außendecke, Wärmestrom nach oben hinterlüftet						
			von Außen nach Innen		Dicke	λ	d / λ
Sand, Kies lufttrocken, Pflanzensubstrat			*		0.1000	2.000	0.050
Bauder Elastomerbitumen-Wurzelschutzbahnen			*		0.0100	0.170	0.059
Brettschichtholz verleimt aussen (475kg/m^3 -Fi/Ta)			*		0.1000	0.120	0.833
Nutzholz (475kg/m^3 -Fi/Ta) gehobelt, techn. getro. dazw.			*	10.0 %	0.1000	0.120	0.083
Luft (1 kg/m^3)			*	90.0 %		0.025	3.600
MDF-Platten mitteldichte Faserplatte (400 kg/m^3)					0.0300	0.100	0.300
Baustrohballen					0.7000	0.049	14.286
Brettschichtholz verleimt aussen (475kg/m^3 -Fi/Ta)					0.0940	0.120	0.783
					Dicke 0.8240		
	RTo 15.5690	RTu 15.5690	RT 15.5690		Dicke gesamt 1.1340	U-Wert	0.06
Nutzholz (475kg/m^3	Achsabstand	0.800 Breite	0.080		Rse+Rsi	0.2	

Atrium building elements detailed planning permit stage

Table 49: Exterior wall atrium-style buildings detailed planning permit stage

AW01 Außenwand				
	von Innen nach Außen	Dicke	λ	d / λ
Lehmputz		0.0300	0.810	0.037
Baustrohballen		0.8000	0.049	16.327
Kalkputz/Voranspritzer		0.0300	0.570	0.053
Kalkputz		0.0100	0.830	0.012
	Rse+Rsi = 0.17	Dicke gesamt 0.8700	U-Wert	0.06

Table 50: Floor construction atrium style buildings detailed planning permit stage

DD01	Außendecke, Wärmestrom nach unten						
			von Innen nach Außen		Dicke	λ	d / λ
Holzboden, Vollholz					0.0100	0.160	0.063
Lehmestrich			F		0.0800	0.160	0.500
Schüttungen aus Sand, Kies, Splitt (1800 kg/m^3)					0.0800	0.700	0.114
Nutzholz (425 kg/m^3) - rauh, luftgetrocknet					0.0240	0.110	0.218
Nutzholz (425 kg/m^3) - gehobelt, techn. getrocknet dazw.				8.7 %	0.7000	0.110	0.553
Baustrohballen				91.3 %		0.050	12.783
Brettschichtholz verleimt aussen (475kg/m^3 -Fi/Ta)					0.0940	0.120	0.783
	RTo 14.7050	RTu 14.5655	RT 14.6352		Dicke gesamt 0.9880	U-Wert	0.07
Nutzholz (425 kg/m^3) -	Achsabstand	0.460 Breite	0.040		Rse+Rsi	0.21	

Table 51: Roof construction atrium-style buildings detailed planning permit stage

FD01 Außendecke, Wärmestrom nach oben hinterlüftet					
von Außen nach Innen			Dicke	λ	d / λ
Sand, Kies lufttrocken, Pflanzensubstrat	*		0.1000	2.000	0.050
Bauder Elastomerbitumen-Wurzelschutzbahnen	*		0.0100	0.170	0.059
Brettschichtholz verleimt aussen (475kg/m³-Fi/Ta)	*		0.1000	0.120	0.833
Nutzholz (475kg/m³-Fi/Ta) gehobelt, techn. getro. dazw.	*	10.0 %	0.1000	0.120	0.083
Luft (1 kg/m³)	*	90.0 %		0.025	3.600
MDF-Platten mitteldichte Faserplatte (400 kg/m³)			0.0300	0.100	0.300
Baustrohballen			0.7000	0.049	14.286
Brettschichtholz verleimt aussen (475kg/m³-Fi/Ta)			0.0940	0.120	0.783
			Dicke 0.8240		
RTo 15.5690 RTu 15.5690 RT 15.5690			Dicke gesamt 1.1340	U-Wert	0.06
Nutzholz (475kg/m³ Achsabstand 0.800 Breite 0.080			Rse+Rsi 0.2		

Table 52: Partition wall construction atrium style-buildings detailed planning permit stage

ZW01 Wand gegen andere Bauwerke an Grundstücks bzw. Bauplatzgrenzen				
von Innen nach Außen		Dicke	λ	d / λ
Lehmputz		0.0300	0.810	0.037
Baustrohballen		0.8000	0.049	16.327
Kalkputz/Voranspritzer		0.0300	0.570	0.053
Kalkputz		0.0100	0.830	0.012
	Rse+Rsi = 0.26	Dicke gesamt 0.8700	U-Wert	0.06

Atrium building elements final planning permit design

Table 53: Exterior wall atrum-style buildings FPPD

AW01 Außenwand				
von Innen nach Außen		Dicke	λ	d / λ
Lehmputz		0.0300	0.810	0.037
Baustrohballen		0.8000	0.050	16.000
Trasskalkputz / -voranspritzer		0.0300	0.570	0.053
Kalkputz		0.0100	0.830	0.012
	Rse+Rsi = 0.17	Dicke gesamt 0.8700	U-Wert	0.06

Table 54: Floor construction atrium-style buildings FPPD

DD01 Außendecke Boden					
von Innen nach Außen			Dicke	λ	d / λ
Holzboden, Vollholz			0.0100	0.160	0.063
Hanf-Lehm-Schüttung	F		0.0700	0.072	0.972
Hanf-Lehm-Schüttung			0.0700	0.072	0.972
Schallschutzplatte			0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)			0.0600	0.120	0.500
Holzträger dazw.		3.3 %	0.7000	0.110	0.212
Stroheinblasdämmung		96.7 %		0.043	15.736
CLT - cross laminated timber (Fichte)			0.0600	0.120	0.500
RTo 19.3253 RTu 19.1574 RT 19.2413			Dicke gesamt 0.9900	U-Wert	0.05
Holzträger: Achsabstand 1.200 Breite 0.040			Rse+Rsi 0.21		

Table 55: Roof construction atrium-style buildings FPPD

FD01 Außendecke					
von Außen nach Innen			Dicke	λ	d / λ
Sand, Kies lufttrocken, Pflanzensubstrat	*		0.0700	2.000	0.035
Schutzschicht - Drainschicht	*		0.0300	0.160	0.188
Wurzelschutzbahnen, dicht	*		0.0100	0.170	0.059
CLT - cross laminated timber (Fichte)	*		0.0900	0.120	0.750
Nutzholz dazw.	*	10.0 %	0.6000	0.120	0.500
Luft (1 kg/m³)	*	90.0 %		0.025	21.600
Holzhartfaserplatte			0.0080	0.220	0.036
MDF-Platte			0.0300	0.100	0.300
Holzträger dazw.		3.3 %	0.7000	0.110	0.212
Stroheinblasdämmung		96.7 %		0.043	15.736
CLT - cross laminated timber (Fichte)			0.0600	0.120	0.500
			Dicke 0.7980		
RTo 16.5751 RTu 16.5117 RT 16.5434			Dicke gesamt 1.5980	U-Wert	0.06
Nutzholz: Achsabstand 0.800 Breite 0.080			Rse+Rsi 0.2		
Holzträger: Achsabstand 1.200 Breite 0.040					

Table 56: Partition wall construction atrium-style buildings FPPD

ZW01	Wand gegen andere Bauwerke an Grundstücks bzw. Bauplatzgrenzen					
		von Innen nach Außen		Dicke	λ	d / λ
Lehmputz				0.0300	0.810	0.037
Baustrohballen				0.8000	0.050	16.000
Trasskalkputz / -voranspritzer				0.0300	0.570	0.053
Kalkputz				0.0100	0.830	0.012
		Rse+Rsi = 0.26	Dicke gesamt	0.8700	U-Wert	0.06

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Table 57: Exterior wall atrum-style buildings FBD

AW01	Außenwand WP DPM F							
			von Innen nach Außen			Dicke	λ	d / λ
3-Schichtplatte Fichte (PEFC)						0.0190	0.120	0.158
Lattung dazw.				7.5 %		0.0270	0.120	0.017
Luft steh., W-Fluss horizontal 20 < d <= 25 mm				92.5 %			0.147	0.170
EGGER EUROSTRAND® OSB 3 E0 CE						0.0250	0.130	0.192
Baustrohballen						0.7600	0.050	15.200
Synthesa Inthermo HFD-Holzfaserdämmplatte						0.0600	0.053	1.132
Kalkputz						0.0100	0.830	0.012
	RTo 17.0515	RTu 17.0510	RT 17.0513		Dicke gesamt	0.9010	U-Wert	0.06
Lattung:	Achsabstand	0.800 Breite	0.060		Rse+Rsi	0.17		

Table 58: Exterior wall with clay atrum-style buildings FBD

AW02	Außenwand WP DPM F Lehm							
			von Innen nach Außen			Dicke	λ	d / λ
Lehmputz						0.0050	0.810	0.006
Lehmbauplatte						0.0160	0.140	0.114
Lattung dazw.				7.5 %		0.0270	0.120	0.017
Luft steh., W-Fluss horizontal 20 < d <= 25 mm				92.5 %			0.147	0.170
EGGER EUROSTRAND® OSB 3 E0 CE						0.0250	0.130	0.192
Baustrohballen						0.7600	0.050	15.200
Synthesa Inthermo HFD-Holzfaserdämmplatte						0.0600	0.053	1.132
Kalkputz						0.0100	0.830	0.012
	RTo 17.0137	RTu 17.0131	RT 17.0134		Dicke gesamt	0.9030	U-Wert	0.06
Lattung:	Achsabstand	0.800 Breite	0.060		Rse+Rsi	0.17		

Table 59: Floor construction atrium-style buildings FBD

DD01	Außendecke Boden WP DPM F							
			von Innen nach Außen			Dicke	λ	d / λ
Mehrschichtparkett						0.0150	0.160	0.094
Gipsfaserplatte (1125 kg/m³)			F			0.0200	0.400	0.050
Holzfaserplatte Variotherm silent						0.0050	0.071	0.070
EGGER EUROSTRAND® OSB 3 E0 CE						0.0250	0.130	0.192
Holzträger dazw.				9.6 %		0.6000	0.110	0.524
Stroheinblasdämmung				90.4 %			0.043	12.614
EGGER DHF						0.0150	0.100	0.150
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.						0.0240	0.120	0.200
	RTo 13.2379	RTu 13.1044	RT 13.1711		Dicke gesamt	0.7040	U-Wert	0.08
Holzträger:	Achsabstand	0.625 Breite	0.060		Rse+Rsi	0.21		

Table 60: Roof construction atrium-style buildings FBD

FD01 Außendecke WP DPM F	von Außen nach Innen		Dicke	λ	d / λ
Z.000.38 Dachdicht. Ethylencopol. ECB	*		0.0020	0.180	0.011
Nutzholz (475kg/m³-Fi/Ta) rauh, techn. getro.	*		0.0240	0.120	0.200
Nutzholz dazw.	*	10.0 %	0.6000	0.120	0.500
Luft (1 kg/m³)	*	90.0 %		0.025	21.600
EGGER DHF			0.0200	0.100	0.200
Holzträger dazw.		7.2 %	0.6000	0.110	0.393
Stroheinblasdämmung		92.8 %		0.043	12.948
EGGER EUROSTRAND® OSB 3 E0 CE			0.0250	0.130	0.192
Nutzholz (475kg/m³-Fi/Ta) gehobelt, techn. getro. dazw.		7.5 %	0.0270	0.120	0.017
Luft steh., W-Fluss n. oben 21 < d <= 25 mm		92.5 %		0.167	0.150
3-Schichtplatte Fichte (PEFC)			0.0190	0.120	0.158
			Dicke 0.6910		

	RTo 13.5670	RTu 13.4613		RT 13.5142	Dicke gesamt 1.3170	U-Wert 0.07
Nutzholz:	Achsabstand	0.800	Breite	0.080	Rse+Rsi 0.2	
Holzträger:	Achsabstand	0.833	Breite	0.060		
Nutzholz (475kg/m³	Achsabstand	0.800	Breite	0.060		

Table 61: Partition wall construction atrium-style buildings FBD

ZW01 Wand gegen andere Bauwerke WP DPM F	von Innen nach Außen	Dicke	λ	d / λ
Lehmputz		0.0050	0.810	0.006
Lehmbauplatte		0.0160	0.140	0.114
Lattung dazw.	7.5 %	0.0300	0.120	0.019
Luft steh., W-Fluss horizontal 20 < d <= 25 mm	92.5 %		0.147	0.189
EGGER EUROSTRAND® OSB 3 E0 CE		0.0250	0.130	0.192
Baustrohballen		0.7600	0.050	15.200
EGGER EUROSTRAND® OSB 3 E0 CE		0.0180	0.130	0.138
FERMACELL Gipsfaser-Platte		0.0100	0.320	0.031
ROCKWOOL Floorrock SE 40-5		0.0200	0.035	0.571

	RTo 16.7214	RTu 16.7208		RT 16.7211	Dicke gesamt 0.8840	U-Wert 0.06
Lattung:	Achsabstand	0.800	Breite	0.060	Rse+Rsi 0.26	

Building compound elements early design stage

Table 62: Exterior wall building compound early design stage

AW01 Außenwand	von Innen nach Außen		Dichte	Dicke	λ	d / λ
Lehmbauplatte			500	0.0150	0.140	0.107
Brettschichtholz verleimt aussen (475kg/m³-Fi/Ta)			475	0.0600	0.120	0.500
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.		2.2 %	425	0.1700	0.110	0.034
Baustrohballen (109kg/m³)		97.8 %	109		0.050	3.326
Baustrohballen (109kg/m³)			109	0.1800	0.050	3.600
Lehmputz			1 700	0.0350	0.810	0.043
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.	*	10.0 %	425	0.0300	0.110	0.027
Luft steh., W-Fluss horizontal 30 < d <= 35 mm	*	90.0 %	1		0.194	0.139
Nutzholz (475kg/m³-Fi/Ta) rauh, luftgetr.	*		475	0.0200	0.120	0.167
				Dicke 0.4600		

	RTo 7.7679	RTu 7.7339		RT 7.7509	Dicke gesamt 0.5100	U-Wert 0.13
Nutzholz (425 kg/m³) -	Achsabstand	0.460	Breite	0.010	Rse+Rsi 0.17	
Nutzholz (425 kg/m³) -	Achsabstand	0.800	Breite	0.080		

Table 63: Floor construction building compound early design stage

DD01 Außendecke, Wärmestrom nach unten	von Innen nach Außen	Dichte	Dicke	λ	d / λ
Holzboden, Vollholz		675	0.0100	0.160	0.063
Lehmestrich		800	0.1000	0.160	0.625
Schüttungen aus Sand, Kies, Splitt (1800 kg/m³)		1 800	0.0800	0.700	0.114
Nutzholz (425 kg/m³) - rauh, luftgetrocknet		425	0.0240	0.110	0.218
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.	8.7 %	425	0.3500	0.110	0.277
Baustrohballen (109kg/m³)	91.3 %	109		0.050	6.391
Brettschichtholz verleimt aussen (475kg/m³-Fi/Ta)		475	0.0180	0.120	0.150

	RTo 7.8114	RTu 7.7186		RT 7.7650	Dicke gesamt 0.5820	U-Wert 0.13
Nutzholz (425 kg/m³) -	Achsabstand	0.460	Breite	0.040	Rse+Rsi 0.21	

Table 64: Roof construction building compound early design stage

FD01 Außendecke, Wärmestrom nach oben hinterlüftet		von Außen nach Innen	Dichte	Dicke	λ	d / λ
MDF-Platten mitteldichte Faserplatte (400 kg/m³)			400	0.0300	0.100	0.300
Baustrohballen (109 kg/m³)			109	0.3500	0.050	7.000
NAPORO hemp			30	0.1500	0.041	3.659
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet			425	0.0200	0.110	0.182
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.	*	15.0 %	425	0.1800	0.110	0.245
Luft (1 kg/m³)	*	85.0 %	1		0.025	6.120
			Dicke	0.5500		

RTo 7.8114 RTu 7.7186 RT 7.7650 Dicke gesamt 0.7300 U-Wert 0.09

Nutzholz (425 kg/m³) - Achsabstand 0.800 Breite 0.120 Rse+Rsi 0.2

Building compound elements detailed planning permit stage

Table 65: Exterior wall building compound detailed planning permit stage

AW02 Außenwand		von Innen nach Außen	Dichte	Dicke	λ	d / λ
Lehmbauplatte			500	0.0200	0.140	0.143
CLT - cross laminated timber (Fichte)			475	0.0400	0.120	0.333
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.		2.2 %	425	0.1700	0.110	0.034
Baustrohballen (109 kg/m³)		97.8 %	109		0.050	3.326
Baustrohballen (109 kg/m³)			109	0.3300	0.050	6.600
Lehmputz			1 700	0.0200	0.810	0.025
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.	*	10.0 %	425	0.0400	0.110	0.036
Luft steh., W-Fluss horizontal 30 < d <= 35 mm	*	90.0 %	1		0.194	0.186
Nutzholz (475kg/m³ -Fi/Ta) rauh,luftgetr.	*		475	0.0300	0.120	0.250
			Dicke	0.5800		

RTo 10.7124 RTu 10.6744 RT 10.6934 Dicke gesamt 0.6500 U-Wert 0.09

Nutzholz (425 kg/m³) - Achsabstand 0.460 Breite 0.010 Rse+Rsi 0.26

Nutzholz (425 kg/m³) - Achsabstand 0.800 Breite 0.080

Table 66: Floor construction building compound detailed planning permit stage

DD02 Außendecke, Wärmestrom nach unten hinterlüftet		von Innen nach Außen	Dichte	Dicke	λ	d / λ
Holzboden, Vollholz			675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung	F		230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung			230	0.0700	0.072	0.972
Schallschutzplatte/Sylomer			92	0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.		8.7 %	425	0.3500	0.110	0.277
Baustrohballen (109 kg/m³)		91.3 %	109		0.050	6.391
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500

RTo 10.3220 RTu 10.1506 RT 10.2363 Dicke gesamt 0.6400 U-Wert 0.10

Nutzholz (425 kg/m³) - Achsabstand 0.460 Breite 0.040 Rse+Rsi 0.34

Table 67: Roof construction building compound detailed planning permit stage

FD01 Außendecke, Wärmestrom nach oben hinterlüftet		von Außen nach Innen	Dichte	Dicke	λ	d / λ
Schutzschicht	*		1 800	0.0500	0.700	0.071
Abdichtung	*		1 200	0.0050	0.170	0.029
CLT - cross laminated timber (Fichte)	*		475	0.0600	0.120	0.500
Nutzholz dazw.	*	10.0 %	475	0.6000	0.120	0.500
Luft (1 kg/m³)	*	90.0 %	1		0.025	21.600
MDF-Platte			400	0.0300	0.100	0.300
Baustrohballen			109	0.7000	0.050	14.000
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Holztram dazw.	*	15.0 %	425	0.1800	0.110	0.245
Luft (1 kg/m³)	*	85.0 %	1		0.025	6.120
			Dicke	0.7900		

RTo 15.0000 RTu 15.0000 RT 15.0000 Dicke gesamt 1.6850 U-Wert 0.07

Nutzholz: Achsabstand 0.800 Breite 0.080 Rse+Rsi 0.2

Holztram: Achsabstand 0.800 Breite 0.120

Table 68: Partition wall construction building compound detailed planning permit stage

ZW03	Zwischenwand zu getrennten Wohn- oder Betriebseinheiten					
	von Innen nach Außen		Dichte	Dicke	λ	d / λ
Lehmbauplatte			500	0.0200	0.140	0.143
NAPORO hemp			30	0.1500	0.041	3.659
Schallschutzplatte (z.B. Capatect Hanf silent)			92	0.0400	0.043	0.930
NAPORO hemp			30	0.1500	0.041	3.659
Lehmbauplatte			500	0.0200	0.140	0.143
	Rse+Rsi = 0.26		**Dicke gesamt**	**0.3800**	**U-Wert**	**0.11**

Table 69: Intermediate ceiling building compound town houses detailed planning permit stage

ZD03	warme Zwischendecke, RH							
		von Innen nach Außen			Dichte	Dicke	λ	d / λ
Holzboden, Vollholz					675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung		F			230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung					230	0.0700	0.072	0.972
Schallschutzplatte/Sylomer					92	0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)					475	0.0600	0.120	0.500
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.			*	15.0 %	425	0.2400	0.110	0.327
Luft (1 kg/m³)			*	85.0 %	1		0.025	8.160
					Dicke	**0.2300**		
	RTo 3.7321	RTu 3.7321	RT 3.7321		**Dicke gesamt**	**0.4700**	**U-Wert**	**0.31**
Nutzholz (425 kg/m³) -	Achsabstand	0.800 Breite	0.120		Rse+Rsi	0.26		

Table 70: Intermediate ceiling building compound apartments detailed planning permit stage

ZD04	warme Zwischendecke, Whg							
		von Innen nach Außen			Dichte	Dicke	λ	d / λ
Holzboden, Vollholz					675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung		F			230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung					230	0.0700	0.072	0.972
CLT - cross laminated timber (Fichte)					475	0.0600	0.120	0.500
Schallschutzplatte/Sylomer					92	0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)					475	0.0600	0.120	0.500
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.			*	15.0 %	425	0.2400	0.110	0.327
Luft (1 kg/m³)			*	85.0 %	1		0.025	8.160
					Dicke	**0.2900**		
	RTo 10.2626	RTu 10.2214	RT 10.2420		**Dicke gesamt**	**0.5300**	**U-Wert**	**0.27**
Nutzholz (425 kg/m³) -	Achsabstand	0.800 Breite	0.120		Rse+Rsi	0.26		

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Table 71: Exterior wall building compound FPPD

AW01	Außenwand hinterlüftet							
		von Innen nach Außen			Dichte	Dicke	λ	d / λ
Lehmbauplatte					500	0.0200	0.140	0.143
OSB - Platte					600	0.0250	0.130	0.192
Nutzholz dazw.				5.0 %	425	0.5000	0.110	0.227
Baustrohballen				95.0 %	105		0.050	9.500
OSB - Platte					600	0.0250	0.130	0.192
Lattung dazw.			*	10.0 %	425	0.0400	0.110	0.036
Luft steh., W-Fluss horizontal 35 < d <= 40 mm			*	90.0 %	1		0.222	0.162
Schalung hinterlüftet			*		475	0.0300	0.120	0.250
					Dicke	**0.5700**		
	RTo 10.2626	RTu 10.2214	RT 10.2420		**Dicke gesamt**	**0.6400**	**U-Wert**	**0.10**
Nutzholz:	Achsabstand	0.800 Breite	0.040		Rse+Rsi	0.26		
Lattung:	Achsabstand	0.800 Breite	0.080					

Table 72: Floor construction building compound FPPD

DD01	**Außendecke**					
		von Innen nach Außen	Dichte	Dicke	λ	d / λ
Holzboden, Vollholz			675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung	F		230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung			230	0.0700	0.072	0.972
Schallschutzplatte			92	0.0200	0.043	0.465
Abdichtungsebene			300	0.0005	0.500	0.001
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Nutzholz dazw.		8.7 %	425	0.3500	0.110	0.277
Baustrohballen		91.3 %	109		0.050	6.391
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
	RTo 10.1902	RTu 10.0216	RT 10.1059	**Dicke gesamt 0.6405**	**U-Wert**	**0.10**
Nutzholz:	Achsabstand	0.460 Breite	0.040	Rse+Rsi 0.21		

Table 73: Roof construction building compound FPPD

FD01	**Außendecke**					
		von Außen nach Innen	Dichte	Dicke	λ	d / λ
Schutzschicht	*		1 800	0.0500	0.700	0.071
Abdichtung	*		1 200	0.0100	0.170	0.059
CLT - cross laminated timber (Fichte)	*		475	0.0900	0.120	0.750
Nutzholz dazw.	*	10.0 %	475	0.6000	0.120	0.500
Luft (1 kg/m³)	*	90.0 %	1		0.025	21.600
MDF-Platte			400	0.0300	0.100	0.300
Baustrohballen			109	0.3500	0.050	7.000
Thermo-Hanf PREMIUM			40	0.0200	0.045	0.444
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Holztram dazw.	*	15.0 %	425	0.1800	0.110	0.245
Luft (1 kg/m³)	*	85.0 %	1		0.025	6.120
				Dicke 0.4600		
	RTo 8.4444	RTu 8.4444	RT 8.4444	**Dicke gesamt 1.3900**	**U-Wert**	**0.12**
Nutzholz:	Achsabstand	0.800 Breite	0.080	Rse+Rsi 0.2		
Holztram:	Achsabstand	0.800 Breite	0.120			

Table 74: Intermediate ceiling building compound town houses FPPD

ZD01	**warme Zwischendecke, RH**					
		von Innen nach Außen	Dichte	Dicke	λ	d / λ
Holzboden, Vollholz			675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung	F		230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung			230	0.0700	0.072	0.972
Schallschutzplatte			92	0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Holztram dazw.	*	15.0 %	425	0.2400	0.110	0.327
Luft (1 kg/m³)	*	85.0 %	1		0.025	8.160
				Dicke 0.2300		
	RTo 3.7321	RTu 3.7321	RT 3.7321	**Dicke gesamt 0.4700**	**U-Wert**	**0.31**
Holztram:	Achsabstand	0.800 Breite	0.120	Rse+Rsi 0.26		

Table 75: Intermediate ceiling building compound apartments FPPD

ZD02	**warme Zwischendecke, Whg**					
		von Innen nach Außen	Dichte	Dicke	λ	d / λ
Holzboden, Vollholz			675	0.0100	0.160	0.063
Hanf-Lehm-Schüttung	F		230	0.0700	0.072	0.972
Hanf-Lehm-Schüttung			230	0.0700	0.072	0.972
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Schallschutzplatte			92	0.0200	0.043	0.465
CLT - cross laminated timber (Fichte)			475	0.0600	0.120	0.500
Holztram dazw.	*	15.0 %	425	0.2400	0.110	0.327
Luft (1 kg/m³)	*	85.0 %	1		0.025	8.160
				Dicke 0.2900		
	RTo 8.4444	RTu 8.4444	RT 8.4444	**Dicke gesamt 0.5300**	**U-Wert**	**0.27**
Holztram:	Achsabstand	0.800 Breite	0.120	Rse+Rsi 0.26		

Building compound elements final building design

Table 76: Exterior wall building compound FBD

AW01 Außenwand	von Innen nach Außen		Dichte	Dicke	λ	d / λ
Brettsperrholz (475 kg/m³)			475	0.1000	0.120	0.833
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.		7.2 %	425	0.4800	0.110	0.315
Stroh Einblasdämmung		92.8 %	109		0.043	10.356
EGGER DHF			600	0.0200	0.100	0.200
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet dazw.	*	6.3 %	425	0.0300	0.110	0.017
Luft steh., W-Fluss horizontal 30 < d <= 35 mm	*	93.8 %	1		0.194	0.145
Nutzholz (525kg/m³-Lärche) rauh,luftgetr.	*		525	0.0240	0.130	0.185
				Dicke 0.6000		

RTo 11.4604 RTu 11.3261 RT 11.3932 **Dicke gesamt 0.6540** **U-Wert** **0.09**

Nutzholz (425 kg/m³) - Achsabstand 0.830 Breite 0.060 Rse+Rsi 0.26

Nutzholz (425 kg/m³) - Achsabstand 0.800 Breite 0.050

Table 77: Floor construction building compound FBD

DD01 Außendecke	von Innen nach Außen		Dichte	Dicke	λ	d / λ
Mehrschichtparkett			740	0.0150	0.160	0.094
Gipsfaserplatte (1125 kg/m³)	F		1 125	0.0200	0.400	0.050
Holzfaserplatte Variotherm silent			250	0.0050	0.071	0.070
EGGER EUROSTRAND® OSB 3 E0 CE			600	0.0250	0.130	0.192
Holzträger dazw.		9.6 %	425	0.4800	0.110	0.419
Stroheinblasdämmung		90.4 %	109		0.043	10.091
EGGER DHF			600	0.0150	0.100	0.150
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.			475	0.0240	0.120	0.200

RTo 10.8060 RTu 10.6768 RT 10.7414 **Dicke gesamt 0.5840** **U-Wert** **0.09**

Holzträger: Achsabstand 0.625 Breite 0.060 Rse+Rsi 0.21

Table 78: Roof construction building compound FBD

FD01 Außendecke, Wärmestrom nach oben hinterlüftet	von Außen nach Innen		Dichte	Dicke	λ	d / λ
Z.000.38 Dachdicht. Ethylencopol. ECB	*		1 100	0.0050	0.180	0.028
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	*		475	0.0240	0.120	0.200
Nutzholz dazw.	*	10.0 %	475	0.6000	0.120	0.500
Luft (1 kg/m³)	*	90.0 %	1		0.025	21.600
EGGER DHF			600	0.0200	0.100	0.200
Holzträger dazw.		7.2 %	425	0.4800	0.110	0.315
Stroheinblasdämmung		92.8 %	109		0.043	10.356
Brettsperrholz (475 kg/m³)			475	0.1000	0.120	0.833
				Dicke 0.6000		

RTo 11.3954 RTu 11.2661 RT 11.3307 **Dicke gesamt 1.2290** **U-Wert** **0.09**

Nutzholz: Achsabstand 0.800 Breite 0.080 Rse+Rsi 0.2

Holzträger: Achsabstand 0.830 Breite 0.060

Table 79: Intermediate ceiling building compound FBD

ZD01 warme Zwischendecke	von Innen nach Außen	Dichte	Dicke	λ	d / λ
Mehrschichtparkett		740	0.0150	0.160	0.094
Gipsfaserplatte (1125 kg/m³)	F	1 125	0.0200	0.400	0.050
Holzfaserplatte Variotherm silent		250	0.0050	0.071	0.070
Brettsperrholz (475 kg/m³)		475	0.1000	0.120	0.833
Luftschicht ruhend (2 mm), aufwärts		1	0.0020	0.045	0.044
EGGER EUROSTRAND® OSB 3 E0 CE		600	0.0180	0.130	0.138
Stroh Einblasdämmung		109	0.0600	0.043	1.395
Brettsperrholz (475 kg/m³)		475	0.1000	0.120	0.833

Rse+Rsi = 0.26 **Dicke gesamt 0.3200** **U-Wert** **0.27**

Parameter for EnergyPlus models FPPD

Table 80: Sum of hours for occupancy for weekdays in the selected living units of FPPD

Occupancy weekdays	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	TR [h]	CA [h]
Atrium East	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	-	-
Atrium West	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	-	-
Top 2	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	-	-
Top 4	8.0	-	-	-	-	-	5.5	-	2.0	-	-
Top 6	8.0	-	-	-	-	-	5.5	-	2.0	-	-
Other	-	-	-	-	-	-	-	-	-	-	0.5

Table 81: Sum of hours for occupancy for weekends in the selected living units of FPPD

Occupancy weekends	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	TR [h]	CA [h]
Atrium East	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Atrium West	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Top 2	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Top 4	9.5	-	-	-	-	-	6.5	-	2.0	-	-
Top 6	9.5	-	-	-	-	-	6.5	-	2.0	-	-
Other	-	-	-	-	-	-	-	-	-	-	1.5

Table 82: Maximum metabolic rates per person for various activities in the selected living units of FPPD

Metabolic rates	Bed1 [W]	Bed2 [W]	Bed3 [W]	SR [W]	EH [W]	HW [W]	LK [W]	WC [W]	Bath [W]	TR [W]	CA [W]
Atrium East	80	300	300	-	-	-	200	130	130	-	-
Atrium West	80	300	300	-	-	-	200	130	130	-	-
Top 2	80	300	300	-	-	-	200	130	130	-	-
Top 4	80	-	-	-	-	-	200	-	130	-	-
Top 6	80	-	-	-	-	-	200	-	130	-	-
Other	-	-	-	-	-	-	-	-	-	-	150

Table 83: Maximum internal gains of standard energy-efficient electric household appliances in the selected living units of FPPD

Electric Equipment	Bed1 [W]	Bed2 [W]	Bed3 [W]	SR [W]	EH [W]	HW [W]	LK [W]	WC [W]	Bath [W]	TR [W]	CA [W]
Atrium East	-	100	100	-	-	-	800	-	600	30	-
Atrium West	-	100	100	-	-	-	800	-	600	30	-
Top 2	-	100	100	-	-	-	800	-	600	-	-
Top 4	-	-	-	-	-	-	800	-	600	-	-
Top 6	-	-	-	-	-	-	800	-	600	-	-
Other	-	-	-	-	-	-	-	-	-	30	300

Table 84: Installed lighting power for the selected living units of FPPD

Lighting power	Bed1 [W]	Bed2 [W]	Bed3 [W]	SR [W]	EH [W]	HW [W]	LK [W]	WC [W]	Bath [W]	TR [W]	CA [W]
Atrium East	32	35	35	13	26	-	127	15	30	15	-
Atrium West	32	35	35	13	26	-	127	15	30	15	-
Top 2	32	35	35	-	26	26	127	15	30	-	-
Top 4	32	-	-	13	26	-	127	-	30	-	-
Top 6	32	-	-	13	26	-	127	-	30	-	-
Other	-	-	-	-	-	-	-	-	-	15	75

Parameter for EnergyPlus models FBD

Table 85: Sum of hours for occupancy for weekdays in the selected living units of FBD

Occupancy weekdays	Bed1 [h]	Bed2 [h]	Bed3 [h]	SR [h]	EH [h]	HW [h]	LK [h]	WC [h]	Bath [h]	OR [h]	CA [h]
Atrium East	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	-	-
Atrium West	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	-	-
Top 2	8.0	10.5	10.5	-	-	-	5.5	2.0	2.0	1	-
Top 4	8.0	-	-	-	-	-	5.5	0.75	1.25	-	-
Top 6	8.0	-	-	-	-	-	5.5	0.75	1.25	-	-
Other	-	-	-	-	-	-	-	-	-	-	0.5

Table 86: Sum of hours for occupancy for weekends in the selected living units of FBD

Occupancy weekends	**Bed1 [h]**	**Bed2 [h]**	**Bed3 [h]**	**SR [h]**	**EH [h]**	**HW [h]**	**LK [h]**	**WC [h]**	**Bath [h]**	**OR [h]**	**CA [h]**
Atrium East	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Atrium West	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Top 2	9.5	13.0	13.0	-	-	-	6.5	2.0	2.0	-	-
Top 4	9.5	-	-	-	-	-	6.5	0.75	1.25	-	-
Top 6	9.5	-	-	-	-	-	6.5	0.75	1.25	-	-
Other	-	-	-	-	-	-	-	-	-	-	1.5

Table 87: Maximum metabolic rates per person for various activities in the selected living units of FBD

Metabolic rates	**Bed1 [W]**	**Bed2 [W]**	**Bed3 [W]**	**SR [W]**	**EH [W]**	**HW [W]**	**LK [W]**	**WC [W]**	**Bath [W]**	**OR [W]**	**CA [W]**
Atrium East	80	300	300	-	-	-	200	130	130	-	-
Atrium West	80	300	300	-	-	-	200	130	130	-	-
Top 2	80	300	300	-	-	-	200	130	130	117	-
Top 4	80	-	-	-	-	-	200	-	130	-	-
Top 6	80	-	-	-	-	-	200	-	130	-	-
Other	-	-	-	-	-	-	-	-	-	-	150

Table 88: Maximum internal gains of standard energy-efficient electric household appliances in the selected living units of FBD

Electric Equipment	**Bed1 [W]**	**Bed2 [W]**	**Bed3 [W]**	**SR [W]**	**EH [W]**	**HW [W]**	**LK [W]**	**WC [W]**	**Bath [W]**	**OR [W]**	**CA [W]**
Atrium East	-	100	100	-	-	-	800	-	600	-	-
Atrium West	-	100	100	-	-	-	800	-	600	-	-
Top 2	-	100	100	-	-	-	800	-	600	300	-
Top 4	-	-	-	-	-	-	800	-	600	-	-
Top 6	-	-	-	-	-	-	800	-	600	-	-
Other	-	-	-	-	-	-	-	-	-	30	300

Table 89: Installed lighting power for the selected living units of FBD

Lighting power	**Bed1 [W]**	**Bed2 [W]**	**Bed3 [W]**	**SR [W]**	**EH [W]**	**HW [W]**	**LK [W]**	**WC [W]**	**Bath [W]**	**OR [W]**	**CA [W]**
Atrium East	32	35	35	13	26	-	127	15	30	-	-
Atrium West	32	35	35	13	26	-	127	15	30	-	-
Top 2	32	35	35	13	26	26	127	15	30	28	-
Top 4	32	-	-	13	26	-	127	15	30	-	-
Top 6	32	-	-	13	26	-	127	15	30	-	-
Other	-	-	-	-	-	-	-	-	-	-	132

Ecological indicators final concepts early design stage

Table 90: Ecological indicators exterior wall atrium-style buildings early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0300	1 700	51.00	0.42	-0.00338	0.000110	21.35	-0.17	0.00561
Baustrohballen (109 kg/m³)	0.8000	109	87.20	0.80	-1.24577	0.000852	69.86	-108.63	0.07429
Trasskalkputz / -voranspritzer	0.0300	1 400	42.00	2.04	0.24883	0.000528	85.81	10.45	0.02218
weber.cal 172 Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**207.46**	**-95.78**	**0.10963**

Table 91: Ecological indicators floor construction atrium-style buildings early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Lehmestrich	0.0800	800	64.00	2.94	-0.02963	0.000627	188.37	-1.90	0.04013
Schüttungen aus Sand, Kies, Splitt (1800 kg/m³)	0.0800	1 800	144.00	0.10	0.00708	0.000048	14.93	1.02	0.00691
Nutzholz (425 kg/m³) - rauh, luftgetrocknet	0.0240	425	10.20	1.74	-1.40521	0.000628	17.70	-14.33	0.00641
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.7000	425	25.87	3.59	-1.43849	0.001283	92.82	-37.21	0.03319
Baustrohballen (109 kg/m³)	0.7000	109	69.67	0.80	-1.24577	0.000852	55.82	-86.79	0.05935
Brettschichtholz verleimt aussen (475kg/m³ -Fi/Ta)	0.0940	475	44.65	8.07	-1.19715	0.002571	360.43	-53.45	0.11480
						Summen:	**755.52**	**-202.76**	**0.26986**

Table 92: Ecological indicators roof construction atrium-style buildings early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Brettschichtholz verleimt aussen (475kg/m³ -Fi/Ta)	0.0940	475	44.65	8.07	-1.19715	0.002571	360.43	-53.45	0.11480
Baustrohballen (109 kg/m³)	0.7000	109	76.30	0.80	-1.24577	0.000852	61.13	-95.05	0.06501
MDF-Platten mitteldichte Faserplatte (400 kg/m³)	0.0300	400	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 1									
Nutzholz (475kg/m³ -Fi/Ta) gehobelt, techn. getro.	0.1000	475	4.75	3.59	-1.43849	0.001283	17.04	-6.83	0.00609
Luft (1 kg/m³)	0.1000	1	0.09	0.00	0.00000	0.000000	0.00	0.00	0.00000
Bauder Elastomerbitumen-Wurzelschutzbahnen	0.0100	1 000	10.00	41.60	0.81917	0.005564	415.96	8.19	0.05564
Sand, Kies lufttrocken, Pflanzensubstrat	0.1000	1 700	170.00	0.31	0.02163	0.000068	52.38	3.68	0.01156
						Summen:	**1 040.68**	**-155.89**	**0.30268**

Table 93: Ecological indicators separating wall atrium-style buildings early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0300	1 700	51.00	0.42	-0.00338	0.000110	21.35	-0.17	0.00561
Baustrohballen (109 kg/m³)	0.8000	109	87.20	0.80	-1.24577	0.000852	69.86	-108.63	0.07429
Trasskalkputz / -voranspritzer	0.0300	1 400	42.00	2.04	0.24883	0.000528	85.81	10.45	0.02218
weber.cal 172 Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**207.46**	**-95.78**	**0.10963**

Table 94: Ecological indicators exterior wall compound early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmbauplatte	0.0150	500	7.50	2.94	-0.02963	0.000627	22.07	-0.22	0.00470
Brettschichtholz verleimt aussen (475kg/m³ -Fi/Ta)	0.0600	475	28.50	8.07	-1.19715	0.002571	230.06	-34.12	0.07327
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.1700	425	1.57	3.59	-1.43849	0.001283	5.64	-2.26	0.00202
Baustrohballen (109 kg/m³)	0.1700	109	18.13	0.80	-1.24577	0.000852	14.52	-22.58	0.01544
Baustrohballen (109 kg/m³)	0.1800	109	19.62	0.80	-1.24577	0.000852	15.72	-24.44	0.01672
Lehmputz	0.0350	1 700	59.50	0.42	-0.00338	0.000110	24.91	-0.20	0.00655
Querschnitt 2									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.0300	425	1.28	3.59	-1.43849	0.001283	4.57	-1.63	0.00164
Luft steh., W-Fluss horizontal 30 < d <= 35 mm	0.0300	1	0.03	0.00	0.00000	0.000000	0.00	0.00	0.00000
Nutzholz (475kg/m³ -Fi/Ta) rauh,luftgetr.	0.0200	475	9.50	1.74	-1.40521	0.000628	16.49	-13.35	0.00597
						Summen:	**333.99**	**-99.01**	**0.12630**

Table 95: Ecological indicators floor construction compound early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Lehmestrich	0.1000	800	80.00	2.94	-0.02963	0.000627	235.46	-2.37	0.05016
Schüttungen aus Sand, Kies, Splitt (1800 kg/m³)	0.0800	1 800	144.00	0.10	0.00708	0.000048	14.93	1.02	0.00691
Nutzholz (425 kg/m³) - rauh, luftgetrocknet	0.0240	425	10.20	1.74	-1.40521	0.000628	17.70	-14.33	0.00641
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.3500	425	12.93	3.59	-1.43849	0.001283	46.41	-18.61	0.01660
Baustrohballen (109 kg/m³)	0.3500	109	34.83	0.80	-1.24577	0.000852	27.91	-43.39	0.02968
Brettschichtholz verleimt aussen (475kg/m³ -Fi/Ta)	0.0180	475	8.55	8.07	-1.19715	0.002571	69.02	-10.24	0.02198
						Summen:	**436.88**	**-98.02**	**0.14081**

Table 96: Ecological indicators roof construction compound early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.1800	425	11.48	3.59	-1.43849	0.001283	41.17	-16.51	0.01472
Luft (1 kg/m³)	0.1800	1	0.15	0.00	0.00000	0.000000	0.00	0.00	0.00000
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.0200	425	8.50	3.59	-1.43849	0.001283	30.50	-12.23	0.01091
NAPORO hemp	0.1500	30	4.50	28.68	0.07735	0.004741	129.06	0.35	0.02133
Baustrohballen (109 kg/m³)	0.3500	109	38.15	0.80	-1.24577	0.000852	30.57	-47.53	0.03250
MDF-Platten mitteldichte Faserplatte (400 kg/m³)	0.0300	400	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 2									
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	0.6000	475	28.50	2.52	-1.49977	0.000944	71.70	-42.74	0.02690
Luft (1 kg/m³)	0.6000	1	0.54	0.00	0.00000	0.000000	0.00	0.00	0.00000
CLT - cross laminated timber (Fichte)	0.0900	475	42.75	6.53	-1.77000	0.001700	279.16	-75.67	0.07268
Abdichtung	0.0100	1 200	12.00	42.87	0.18542	0.005465	514.48	2.23	0.06558
Schutzschicht	0.0500	1 800	90.00	0.02	0.00000	0.000010	1.80	0.00	0.00090
						Summen:	**1 232.16**	**-204.52**	**0.29511**

Table 97: Ecological indicators separating wall compound early design stage

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Lehmestrich	0.1000	800	80.00	2.94	-0.02963	0.000627	235.46	-2.37	0.05016
Schafwolle-Dämmfilz (37 kg/m³)	0.0100	37	0.37	19.74	0.53711	0.004116	7.30	0.20	0.00152
Schüttungen aus Sand, Kies, Splitt (1800 kg/m³)	0.0500	1 800	90.00	0.10	0.00708	0.000048	9.33	0.64	0.00432
Querschnitt 2									
Nutzholz (475kg/m³ -Fi/Ta) gehobelt, techn. getro.	0.1800	475	8.55	3.59	-1.43849	0.001283	30.68	-12.30	0.01097
NAPORO hemp	0.1800	30	4.86	28.68	0.07735	0.004741	139.38	0.38	0.02304
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.0200	425	8.50	3.59	-1.43849	0.001283	30.50	-12.23	0.01091
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.1800	425	11.48	3.59	-1.43849	0.001283	41.17	-16.51	0.01472
Luft (1 kg/m³)	0.1800	1	0.15	0.00	0.00000	0.000000	0.00	0.00	0.00000
						Summen:	**519.27**	**-52.29**	**0.12472**

Table 98: Ecological indicators constructions early design stage

Atrium East	**Surface [m²]**	**PEI [MJ]**	**GWP [kg CO_2]**	**AP [kg SO_2]**
Exterior wall	186.8	38754.2	-17892.2	20.5
Floor construction	151.9	114763.1	-30799.4	41.0
Roof construction	151.9	158079.0	-23679.7	46.0
Separation wall	26.0	5394.1	-2490.4	2.9
Windows/doors	45.5	45804.9	1432.5	17.6
Total		362795	-73430	128
Atrium West				
Exterior wall	185.3	38443.0	-17748.9	20.3
Floor construction	151.9	114763.1	-30799.4	41.0
Roof construction	151.9	158079.0	-23679.7	46.9
Separation wall	27.3	5663.8	-2614.9	3.0
Windows/doors	45.5	45804.9	1432.5	17.6
Total		362754	-73410	128
Compound				
Exterior wall	484.8	161919.4	-47999.8	61.2
Floor construction	394.1	172173.4	-38628.8	55.5
Roof construction	394.1	485592.7	-80600.9	46.3
Interior ceiling	394.1	204643.6	-20607.2	49.2
Windows/doors	183.5	140119.1	4725.0	61.4
Total		1164448	-183112	344

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Table 99: Ecological indicators exterior wall atrium-style buildings FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0300	1 700	51.00	0.42	-0.00338	0.000110	21.35	-0.17	0.00561
Baustrohballen (109 kg/m³)	0.8000	109	87.20	0.80	-1.24577	0.000852	69.86	-108.63	0.07429
Trasskalkputz / -voranspritzer	0.0300	1 400	42.00	2.04	0.24883	0.000528	85.81	10.45	0.02218
weber.cal 172 Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**207.46**	**-95.78**	**0.10963**

Table 100: Ecological indicators floor construction atrium-style buildings FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Schallschutzplatte	0.0200	92	1.84	14.70	-0.67400	0.003612	27.05	-1.24	0.00665
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Querschnitt 1									
Hölzträger	0.7000	425	9.92	3.59	-1.43849	0.001283	35.58	-14.27	0.01272
Stroheinblasdämmung	0.7000	105	71.05	0.80	-1.24577	0.000852	56.93	-88.51	0.06053
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
						Summen:	**691.59**	**-224.81**	**0.22599**

Table 101: Ecological indicators roof construction atrium-style buildings FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Querschnitt 1									
Holzträger	0.7000	425	9.92	3.59	-1.43849	0.001283	35.58	-14.27	0.01272
Stroheinblasdämmung	0.7000	105	71.05	0.80	-1.24577	0.000852	56.93	-88.51	0.06053
MDF-Platte	0.0300	400	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Holzhartfaserplatte	0.0080	1 000	8.00	11.89	-0.98275	0.001765	95.11	-7.86	0.01412
Querschnitt 2									
Nutzholz	0.6000	475	28.50	3.59	-1.43849	0.001283	102.26	-41.00	0.03657
Luft (1 kg/m³)	0.6000	1	0.54	0.00	0.00000	0.000000	0.00	0.00	0.00000
CLT - cross laminated timber (Fichte)	0.0900	475	42.75	6.53	-1.77000	0.001700	279.16	-75.67	0.07268
Wurzelschutzbahn, dicht	0.0100	1 000	10.00	41.60	0.81917	0.005564	415.96	8.19	0.05564
Schutzschicht - Drainschicht	0.0300	400	12.00	2.20	0.30996	0.000769	26.41	3.72	0.00923
Sand, Kies lufttrocken, Pflanzensubstrat	0.0700	1 700	119.00	0.31	0.02163	0.000068	36.67	2.57	0.00809
						Summen:	**1 367.89**	**-275.68**	**0.36761**

Table 102: Ecological indicators separating wall atrium-style buildings FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0300	1 700	51.00	0.42	-0.00338	0.000110	21.35	-0.17	0.00561
Baustrohballen (109 kg/m³)	0.8000	109	87.20	0.80	-1.24577	0.000852	69.86	-108.63	0.07429
Trasskalkputz / -voranspritzer	0.0300	1 400	42.00	2.04	0.24883	0.000528	85.81	10.45	0.02218
weber.cal 172 Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**207.46**	**-95.78**	**0.10963**

Table 103: Ecological indicators exterior wall compound FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmbauplatte	0.0200	500	10.00	2.94	-0.02963	0.000627	29.43	-0.30	0.00627
OSB - Platte	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Querschnitt 1									
Nutzholz	0.5000	425	10.63	3.59	-1.43849	0.001283	38.12	-15.28	0.01363
Baustrohballen	0.5000	105	49.88	0.80	-1.24577	0.000852	39.96	-62.13	0.04249
OSB - Platte	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Querschnitt 2									
Lattung	0.0400	425	1.70	3.59	-1.43849	0.001283	6.10	-2.45	0.00218
Luft steh., W-Fluss horizontal 35 < d <= 40 mm	0.0400	1	0.04	0.00	0.00000	0.000000	0.00	0.00	0.00000
Schalung hinterlüftet	0.0300	475	14.25	1.74	-1.40521	0.000628	24.73	-20.02	0.00895
						Summen:	**395.04**	**-134.73**	**0.13641**

Table 104: Ecological indicators floor construction compound FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Schallschutzplatte	0.0200	92	1.84	14.70	-0.67400	0.003612	27.05	-1.24	0.00665
Abdichtungsebene	0.0005	300	0.15	87.82	2.83275	0.008682	13.17	0.42	0.00130
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Querschnitt 1									
Nutzholz	0.3500	425	12.93	3.59	-1.43849	0.001283	46.41	-18.61	0.01660
Baustrohballen	0.3500	109	34.83	0.80	-1.24577	0.000852	27.91	-43.39	0.02968
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
						Summen:	**686.57**	**-183.61**	**0.20031**

Table 105: Ecological indicators roof construction compound FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Querschnitt 1									
Holztram	0.1800	425	11.48	3.59	-1.43849	0.001283	41.17	-16.51	0.01472
Luft (1 kg/m³)	0.1800	1	0.15	0.00	0.00000	0.000000	0.00	0.00	0.00000
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Thermo-Hanf PREMIUM	0.0200	40	0.80	28.68	0.07735	0.004741	22.94	0.06	0.00379
Baustrohballen	0.3500	109	38.15	0.80	-1.24577	0.000852	30.57	-47.53	0.03250
MDF-Platte	0.0300	400	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 2									
Nutzholz	0.6000	475	28.50	3.59	-1.43849	0.001283	102.26	-41.00	0.03657
Luft (1 kg/m³)	0.6000	1	0.54	0.00	0.00000	0.000000	0.00	0.00	0.00000
CLT - cross laminated timber (Fichte)	0.0900	475	42.75	6.53	-1.77000	0.001700	279.16	-75.67	0.07268
Abdichtung	0.0100	1 200	12.00	42.87	0.18542	0.005465	514.48	2.23	0.06558
Schutzschicht	0.0500	1 800	90.00	0.02	0.00000	0.000010	1.80	0.00	0.00090
						Summen:	**1 312.20**	**-241.28**	**0.32477**

Table 106: Ecological indicators interior ceiling 1 compound FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Schallschutzplatte	0.0200	92	1.84	14.70	-0.67400	0.003612	27.05	-1.24	0.00665
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Querschnitt 1									
Holztram	0.2400	425	15.30	3.59	-1.43849	0.001283	54.90	-22.01	0.01963
Luft (1 kg/m³)	0.2400	1	0.20	0.00	0.00000	0.000000	0.00	0.00	0.00000
						Summen:	**467.87**	**-93.60**	**0.12391**

Table 107: Ecological indicators interior ceiling 2 compound FPPD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Holzboden, Vollholz	0.0100	675	6.75	3.77	-1.49590	0.001345	25.45	-10.10	0.00908
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
Hanf-Lehm-Schüttung	0.0700	100	7.00	12.46	-0.70052	0.002865	87.19	-4.90	0.02005
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Schallschutzplatte	0.0200	92	1.84	14.70	-0.67400	0.003612	27.05	-1.24	0.00665
CLT - cross laminated timber (Fichte)	0.0600	475	28.50	6.53	-1.77000	0.001700	186.11	-50.45	0.04845
Querschnitt 1									
Holztram	0.2400	425	15.30	3.59	-1.43849	0.001283	54.90	-22.01	0.01963
Luft (1 kg/m³)	0.2400	1	0.20	0.00	0.00000	0.000000	0.00	0.00	0.00000
						Summen:	**653.98**	**-144.04**	**0.17236**

Table 108: Ecological indicators constructions FPPD

Atrium East	**Surface [m²]**	**PEI [MJ]**	**GWP [kg CO_2]**	**AP [kg SO_2]**
Exterior wall	175.3	36368.4	-16791.1	19.2
Floor construction	151.7	104913.8	-34104.0	34.3
Roof construction	151.0	206551.9	-41628.4	55.5
Separation wall	28.0	5809.0	-2682.0	3.1
Windows/doors	42.9	38931.4	1463.2	15.9
Total		392574	-93742	128
Atrium West				
Exterior wall	177.4	36804.1	-16992.2	19.4
Floor construction	151.7	104913.8	-34104.0	34.3
Roof construction	151.0	206551.9	-41628.4	55.5
Separation wall	28.0	5809.0	-2682.0	3.1
Windows/doors	40.7	35281.8	1295.8	14.7
Total		389361	-94111	127
Compound				
**Exterior wall	530.1	209412.8	-71418.2	72.3
Floor construction	404.5	277718.2	-74270.2	81.0
Roof construction	404.5	530786.6	-97596.4	131.4
Interior ceiling 1	149.0	69713.0	-13946.2	18.5
Interior ceiling 2	227.7	148910.6	-32798.7	39.2
Windows/doors	210.9	187619.0	5183.6	75.5
Total		1424160	-284846	418

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Table 109: Ecological indicators exterior wall atrium-style buildings FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
3-Schichtplatte Fichte (PEFC)	0.0190	490	9.31	9.20	-1.00318	0.002681	85.67	-9.34	0.02682
Querschnitt 1									
Lattung	0.0270	475	0.96	3.59	-1.43849	0.001283	3.45	-1.38	0.00123
Luft steh., W-Fluss horizontal 20 < d <= 25 mm	0.0270	1	0.02	0.00	0.00000	0.000000	0.00	0.00	0.00000
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Baustrohballen	0.7600	109	82.84	0.80	-1.24577	0.000852	66.37	-103.20	0.07058
Synthesa Inthermo HFD-Holzfaserdämmplatte	0.0600	250	15.00	14.40	-0.80420	0.004000	215.93	-12.06	0.06000
Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**530.21**	**-140.69**	**0.19762**

Table 110: Ecological indicators exterior wall clay atrium-style buildings FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0050	1 700	8.50	0.42	-0.00338	0.000110	3.56	-0.03	0.00094
Lehmbauplatte	0.0160	500	8.00	2.94	-0.02963	0.000627	23.55	-0.24	0.00502
Querschnitt 1									
Lattung	0.0270	475	0.96	3.59	-1.43849	0.001283	3.45	-1.38	0.00123
Luft steh., W-Fluss horizontal 20 < d <= 25 mm	0.0270	1	0.02	0.00	0.00000	0.000000	0.00	0.00	0.00000
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Baustrohballen	0.7600	109	82.84	0.80	-1.24577	0.000852	66.37	-103.20	0.07058
Synthesa Inthermo HFD-Holzfaserdämmplatte	0.0600	250	15.00	14.40	-0.80420	0.004000	215.93	-12.06	0.06000
Kalkputz	0.0100	1 440	14.40	2.11	0.17835	0.000524	30.43	2.57	0.00755
						Summen:	**471.65**	**-131.62**	**0.17675**

Table 111: Ecological indicators floor construction atrium-style buildings FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Mehrschichtparkett	0.0150	740	11.10	17.19	0.34804	0.005625	190.85	3.86	0.06244
Gipsfaserplatte (1125 kg/m³)	0.0200	1 125	22.50	5.44	0.08709	0.001472	122.41	1.96	0.03312
Holzfaserplatte Variotherm silent	0.0050	250	1.25	14.40	-0.80420	0.004000	17.99	-1.01	0.00500
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Querschnitt 1									
Holzträger	0.6000	425	24.48	3.59	-1.43849	0.001283	87.83	-35.21	0.03141
Stroheinblasdämmung	0.6000	105	56.95	0.80	-1.24577	0.000852	45.63	-70.95	0.04852
EGGER DHF	0.0150	600	9.00	11.14	-1.03509	0.004132	100.29	-9.32	0.03719
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	0.0240	475	11.40	2.52	-1.49977	0.000944	28.68	-17.10	0.01076
						Summen:	**722.04**	**-145.03**	**0.25988**

Table 112: Ecological indicators roof construction atrium-style buildings FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
3-Schichtplatte Fichte (PEFC)	0.0190	490	9.31	9.20	-1.00318	0.002881	85.67	-9.34	0.02682
Querschnitt 1									
Nutzholz (475kg/m³ -Fi/Ta) gehobelt, techn. getro.	0.0270	475	0.96	3.59	-1.43849	0.001283	3.45	-1.38	0.00123
Luft steh., W-Fluss n. oben 21 < d <= 25 mm	0.0270	1	0.02	0.00	0.00000	0.000000	0.00	0.00	0.00000
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Querschnitt 2									
Holzträger	0.6000	425	18.37	3.59	-1.43849	0.001283	65.90	-26.42	0.02357
Stroheinblasdämmung	0.6000	105	58.46	0.80	-1.24577	0.000852	46.84	-72.83	0.04981
EGGER DHF	0.0200	600	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 3									
Nutzholz	0.6000	475	28.50	3.59	-1.43849	0.001283	102.26	-41.00	0.03657
Luft (1 kg/m³)	0.6000	1	0.54	0.00	0.00000	0.000000	0.00	0.00	0.00000
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	0.0240	475	11.40	2.52	-1.49977	0.000944	28.68	-17.10	0.01076
Z.000.38 Dachdicht. Ethylencopol. ECB	0.0020	1 100	2.20	41.60	0.81917	0.005564	91.51	1.80	0.01224
						Summen:	**686.39**	**-195.96**	**0.24202**

Table 113: Ecological indicators separating wall atrium-style buildings FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Lehmputz	0.0050	1 700	8.50	0.42	-0.00338	0.000110	3.56	-0.03	0.00094
Lehmbauplatte	0.0160	500	8.00	2.94	-0.02963	0.000627	23.55	-0.24	0.00502
Querschnitt 1									
Lattung	0.0300	475	1.07	3.59	-1.43849	0.001283	3.83	-1.54	0.00137
Luft steh., W-Fluss horizontal 20 < d <= 25 mm	0.0300	1	0.03	0.00	0.00000	0.000000	0.00	0.00	0.00000
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Baustrohballen	0.7600	109	82.84	0.80	-1.24577	0.000852	66.37	-103.20	0.07058
EGGER EUROSTRAND® OSB 3 E0 CE	0.0180	600	10.80	8.56	-1.15143	0.002096	92.41	-12.44	0.02264
FERMACELL Gipsfaser-Platte	0.0100	1 150	11.50	5.44	0.08709	0.001472	62.56	1.00	0.01693
ROCKWOOL Floorrock SE 40-5	0.0200	105	2.10	21.36	1.93455	0.014126	44.86	4.06	0.02966
						Summen:	**425.50**	**-129.65**	**0.17857**

Table 114: Ecological indicators exterior wall compound FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Brettsperrholz (475 kg/m³)	0.1000	475	47.50	7.46	-1.10341	0.002263	354.52	-52.41	0.10749
Querschnitt 1									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.4800	425	14.75	3.59	-1.43849	0.001283	52.91	-21.21	0.01892
Stroh Einblasdämmung	0.4800	109	48.54	0.80	-1.24577	0.000852	38.89	-60.47	0.04135
EGGER DHF	0.0200	600	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 2									
Nutzholz (425 kg/m³) - gehobelt, techn. getrocknet	0.0300	425	0.80	3.59	-1.43849	0.001283	2.86	-1.15	0.00102
Luft steh., W-Fluss horizontal 30 < d <= 35 mm	0.0300	1	0.03	0.00	0.00000	0.000000	0.00	0.00	0.00000
Nutzholz (525kg/m³-Lärche) rauh,luftgetr.	0.0240	525	12.60	2.08	-1.68625	0.000754	26.24	-21.25	0.00950
						Summen:	**609.15**	**-168.91**	**0.22787**

Table 115: Ecological indicators floor construction compound FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Mehrschichtparkett	0.0150	740	11.10	17.19	0.34804	0.005625	190.85	3.86	0.06244
Gipsfaserplatte (1125 kg/m³)	0.0200	1 125	22.50	5.44	0.08709	0.001472	122.41	1.96	0.03312
Holzfaserplatte Variotherm silent	0.0050	250	1.25	14.40	-0.80420	0.004000	17.99	-1.01	0.00500
EGGER EUROSTRAND® OSB 3 E0 CE	0.0250	600	15.00	8.56	-1.15143	0.002096	128.35	-17.27	0.03144
Querschnitt 1									
Holzträger	0.4800	425	19.58	3.59	-1.43849	0.001283	70.27	-28.17	0.02513
Stroheinblasdämmung	0.4800	109	47.30	0.80	-1.24577	0.000852	37.89	-58.92	0.04030
EGGER DHF	0.0150	600	9.00	11.14	-1.03509	0.004132	100.29	-9.32	0.03719
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	0.0240	475	11.40	2.52	-1.49977	0.000944	28.68	-17.10	0.01076
						Summen:	**696.74**	**-125.96**	**0.24537**

Table 116: Ecological indicators roof construction compound FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Brettsperrholz (475 kg/m³)	0.1000	475	47.50	7.46	-1.10341	0.002263	354.52	-52.41	0.10749
Querschnitt 1									
Holzträger	0.4800	425	14.75	3.59	-1.43849	0.001283	52.91	-21.21	0.01892
Stroheinblasdämmung	0.4800	109	48.54	0.80	-1.24577	0.000852	38.89	-60.47	0.04135
EGGER DHF	0.0200	600	12.00	11.14	-1.03509	0.004132	133.73	-12.42	0.04958
Querschnitt 2									
Nutzholz	0.6000	475	28.50	3.59	-1.43849	0.001283	102.26	-41.00	0.03657
Luft (1 kg/m³)	0.6000	1	0.54	0.00	0.00000	0.000000	0.00	0.00	0.00000
Nutzholz (475kg/m³ -Fi/Ta) rauh, techn. getro.	0.0240	475	11.40	2.52	-1.49977	0.000944	28.68	-17.10	0.01076
Z.000.38 Dachdicht. Ethylencopol. ECB	0.0050	1 100	5.50	41.60	0.81917	0.005564	228.78	4.51	0.03060
						Summen:	**939.77**	**-200.10**	**0.29528**

Table 117: Ecological indicators interior ceiling compound FBD

	d [m]	Dichte [kg/m³]	flächenspez. Masse [kg/m²]	PEI [MJ/kg]	GWP [kg CO2 equi. /kg]	AP [kg SO2 equi./kg]	PEI [MJ/m²]	GWP [kg CO2 equi./m²]	AP [kg SO2 equi./m²]
Mehrschichtparkett	0.0150	740	11.10	17.19	0.34804	0.005625	190.85	3.86	0.06244
Gipsfaserplatte (1125 kg/m³)	0.0200	1 125	22.50	5.44	0.08709	0.001472	122.41	1.96	0.03312
Holzfaserplatte Variotherm silent	0.0050	250	1.25	14.40	-0.80420	0.004000	17.99	-1.01	0.00500
Brettsperrholz (475 kg/m³)	0.1000	475	47.50	7.46	-1.10341	0.002263	354.52	-52.41	0.10749
Luftschicht ruhend (2 mm), aufwärts	0.0020	1	0.00	0.00	0.00000	0.000000	0.00	0.00	0.00000
EGGER EUROSTRAND® OSB 3 E0 CE	0.0180	600	10.80	8.56	-1.15143	0.002096	92.41	-12.44	0.02264
Stroh Einblasdämmung	0.0600	109	6.54	0.80	-1.24577	0.000852	5.24	-8.15	0.00557
Brettsperrholz (475 kg/m³)	0.1000	475	47.50	7.46	-1.10341	0.002263	354.52	-52.41	0.10749
						Summen:	**1 137.95**	**-120.59**	**0.34375**

Climate locations of the atrium-style buildings

Table 118: Indoor temperatures of Atrium East for the selected locations

Hours with temperatures > 26 °C for Atrium East	Standard HSP [h]	Adapted HSP [h]	Low FC [h]	High FC [h]
Böheimkirchen	1701	1719	701	292
Vienna	1840	1865	927	376
Innsbruck	683	712	264	236
Klagenfurt	1140	1140	352	213
Mallnitz	201	173	199	199

Table 119 Indoor temperatures of Atrium West for the selected locations

Hours with temperatures > 26 °C for Atrium West	Standard HSP [h]	Adapted HSP [h]	Low FC [h]	High FC [h]
Böheimkirchen	1682	1696	688	293
Vienna	1821	1844	912	376
Innsbruck	652	676	255	226
Klagenfurt	1114	1108	330	203
Mallnitz	204	175	202	202

Table 120: Heating demands of the Atrium East building for the selected locations

Heating intensities [kWh/(m²a)]	GEQ HWB_RK	GEQ HWB_SK	EP+ Standard HSP	EP+ Adapted HSP	EP+ Low FC	EP+ High FC
Böheimkirchen	18.18	20.17	18.12	24.98	18.19	18.20
Vienna	18.18	19.53	17.41	24.24	17.48	17.49
Innsbruck	18.18	21.33	14.03	21.01	14.06	14.07
Klagenfurt	18.18	19.90	17.36	24.32	17.42	17.42
Mallnitz	18.18	22.49	15.86	22.84	15.87	15.87

Table 121: Heating demands of the Atrium West building for the selected locations

Heating intensities [kWh/(m²a)]	GEQ HWB_RK	GEQ HWB_SK	EP+ Standard HSP	EP+ Adapted HSP	EP+ Low FC	EP+ High FC
Böheimkirchen	18.57	20.58	18.13	25.14	18.19	18.20
Vienna	18.57	19.92	17.43	24.41	17.50	17.51
Innsbruck	18.57	21.86	14.13	21.30	14.17	14.18
Klagenfurt	18.57	20.40	17.44	24.56	17.49	17.50
Mallnitz	18.57	23.30	16.04	23.16	16.05	16.05

B. Figures

Ventilation scenarios detailed planning permit stage Atrium West

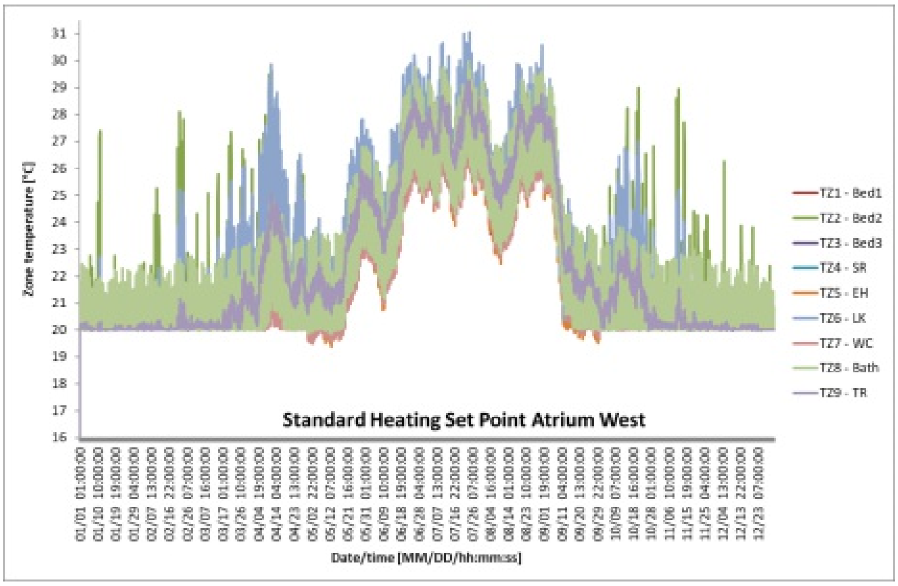

Figure 74: Indoor air temperatures for the standard HSP model of the Atrium West building

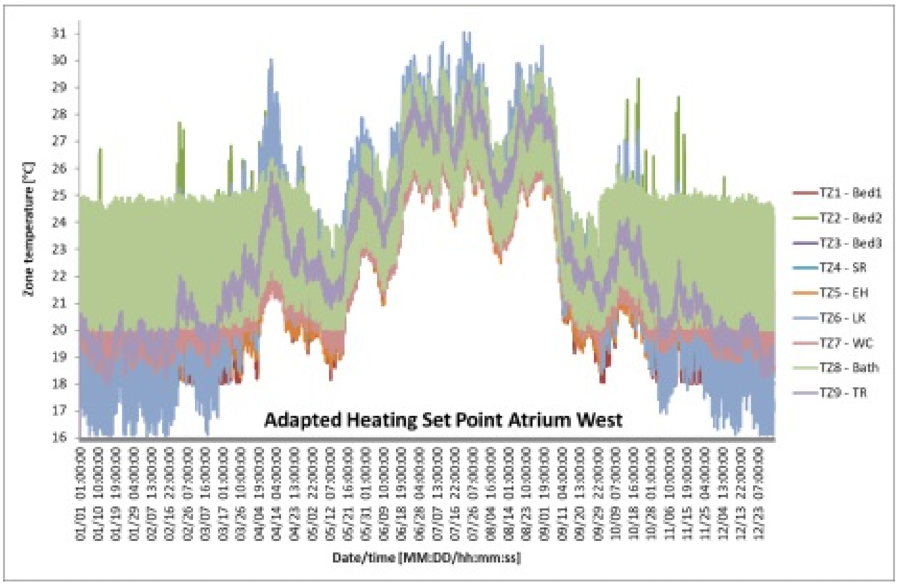

Figure 75: Indoor air temperatures for the adapted HSP model of the Atrium West building

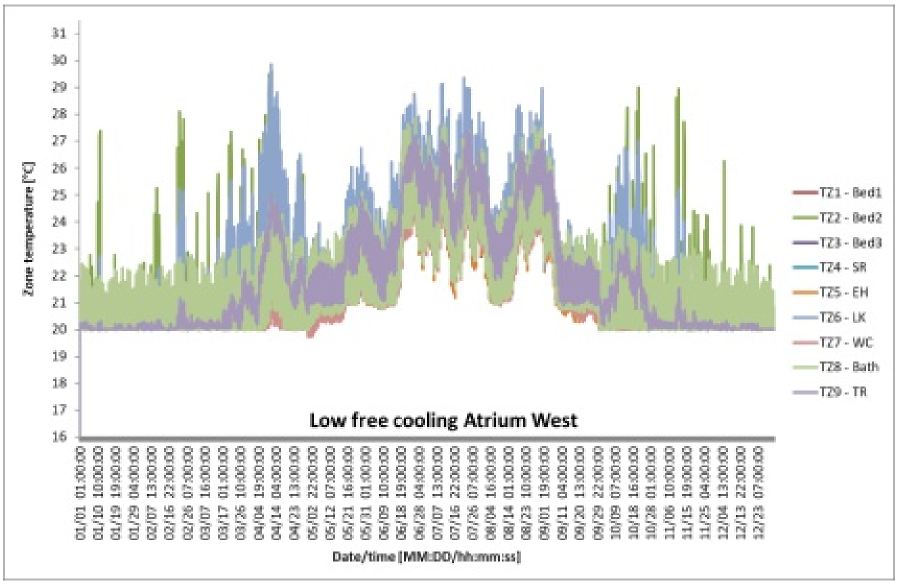

Figure 76: Indoor air temperatures for the low FC model of the Atrium West building

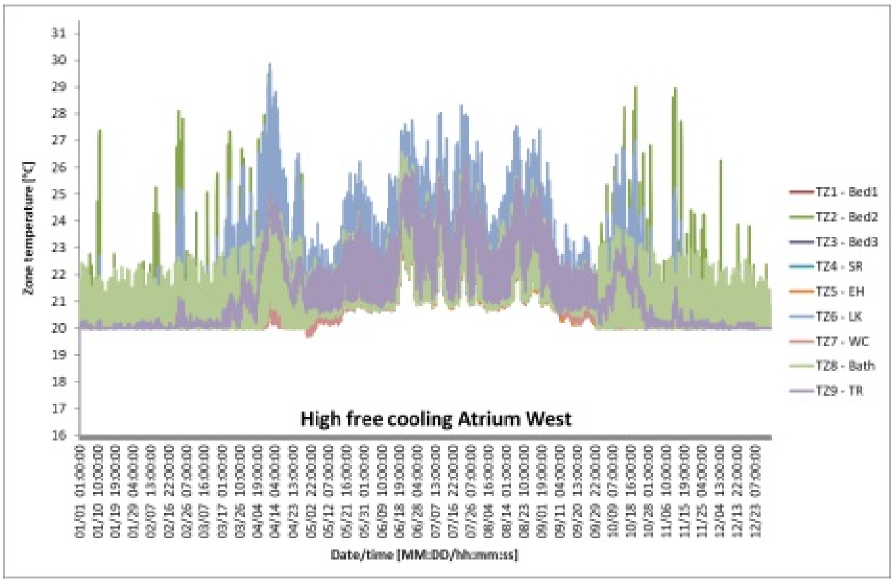

Figure 77: Indoor air temperatures for the high FC model of the Atrium West building

Ventilation scenarios detailed planning permit stage compound

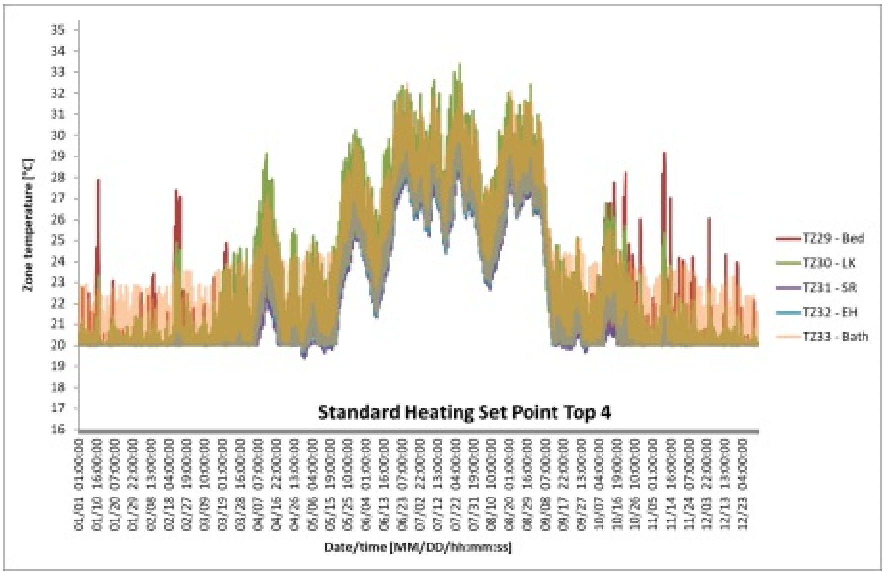

Figure 78: Indoor air temperatures for the standard HSP model of Top 4

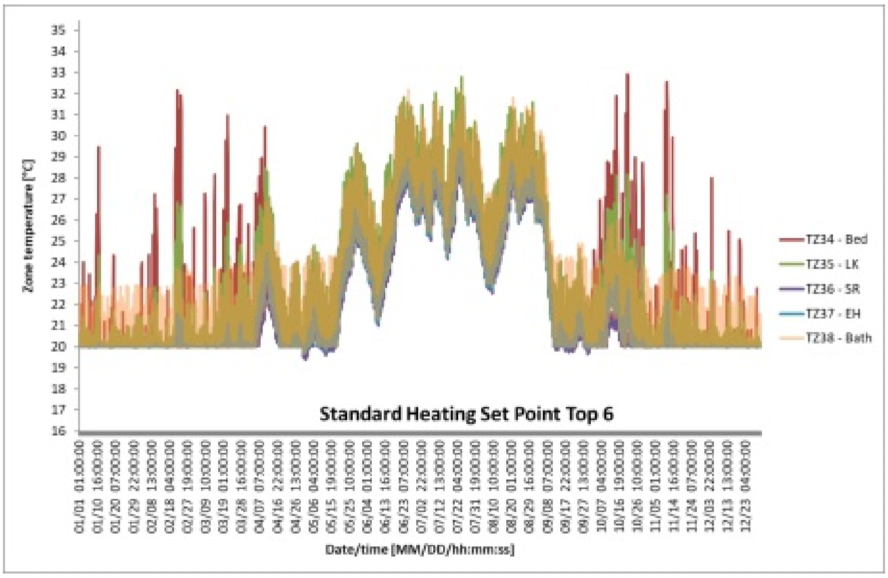

Figure 79: Indoor air temperatures for the standard HSP model of Top 6

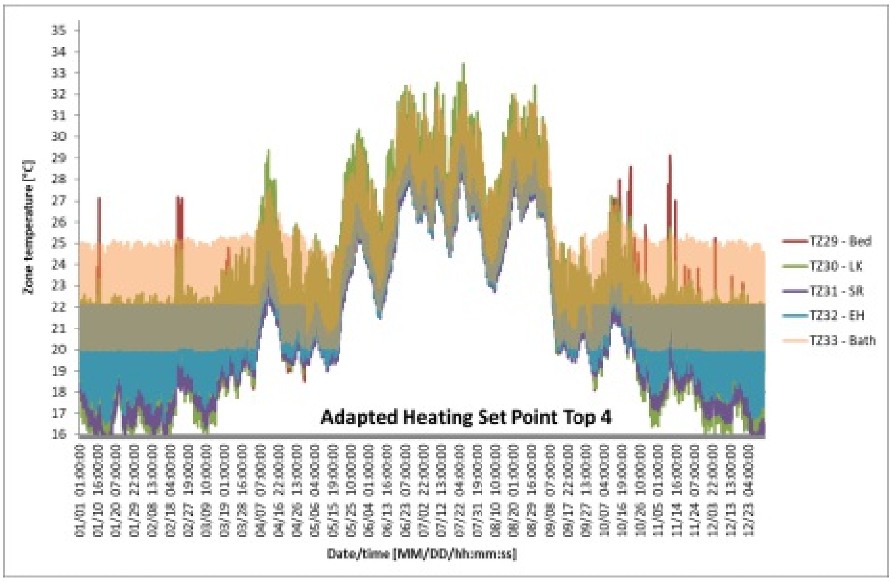

Figure 80: Indoor air temperatures for the adapted HSP model of Top 4

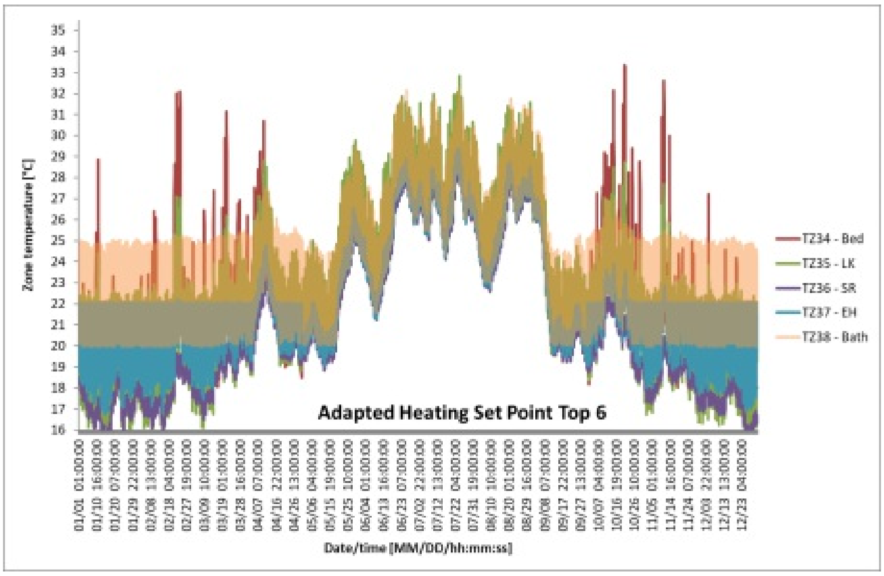

Figure 81: Indoor air temperatures for the adapted HSP model of Top 6

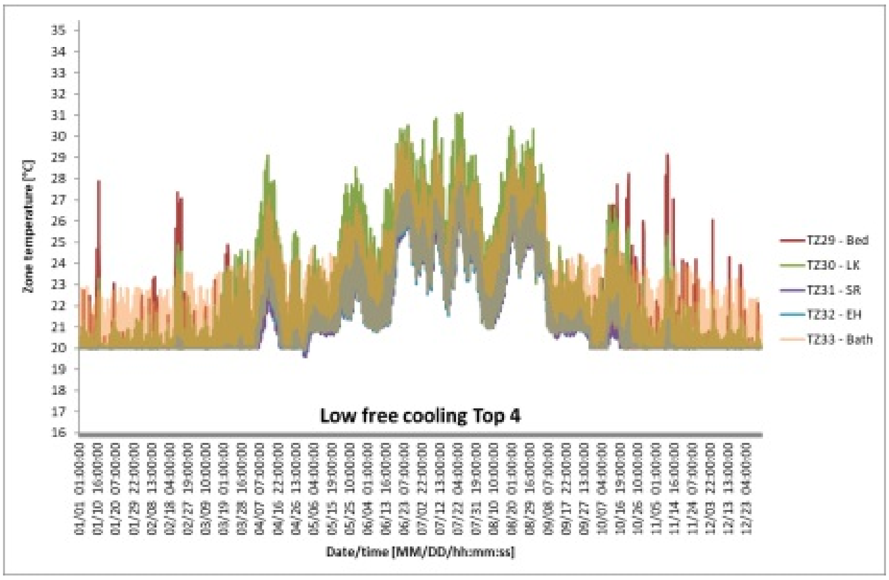

Figure 82: Indoor air temperatures for the low FC model of Top 4

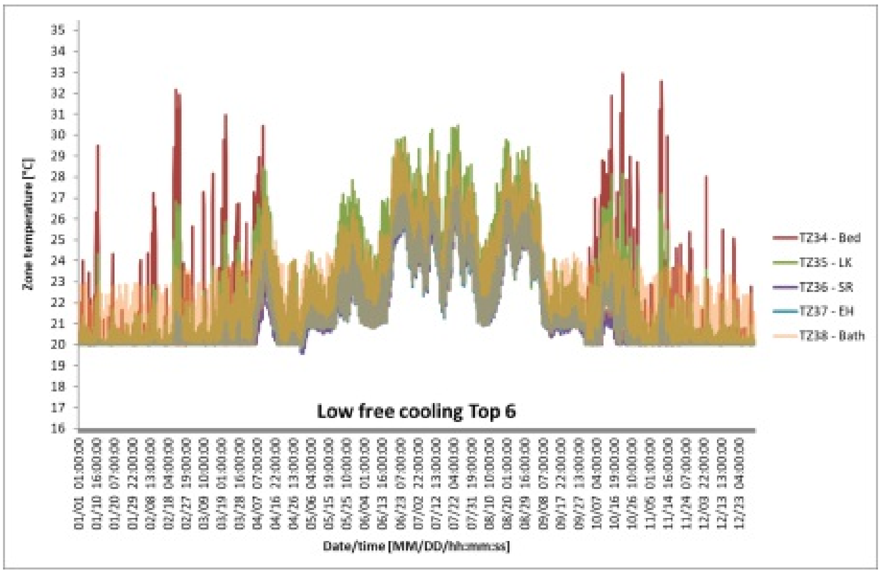

Figure 83: Indoor air temperatures for the low FC model of Top 6

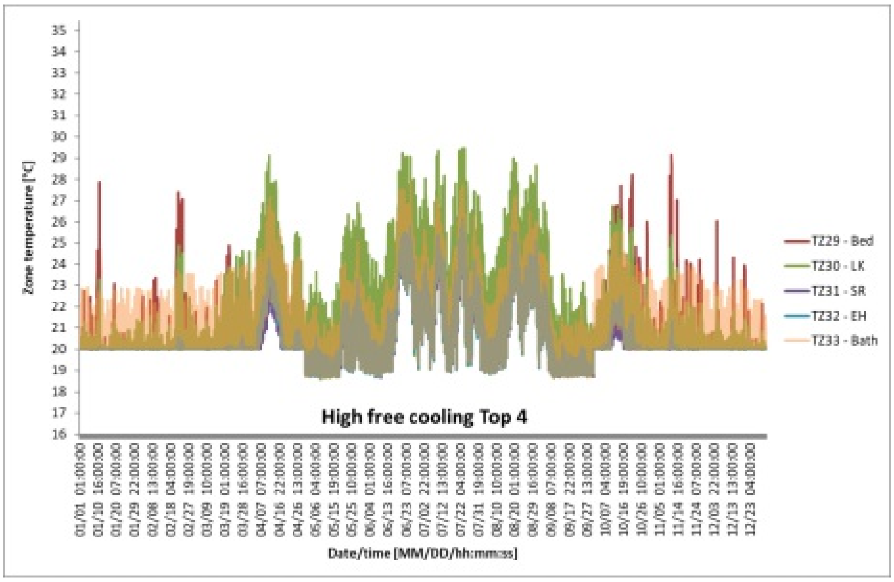

Figure 84: Indoor air temperatures for the high FC model of Top 4

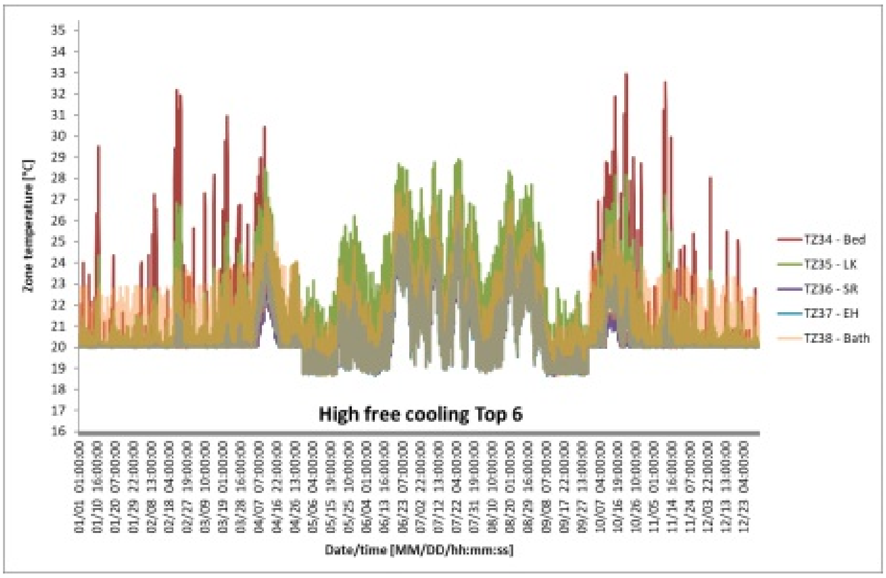

Figure 85: Indoor air temperatures for the high FC model of Top 6

Ventilation scenarios final building design Atrium West

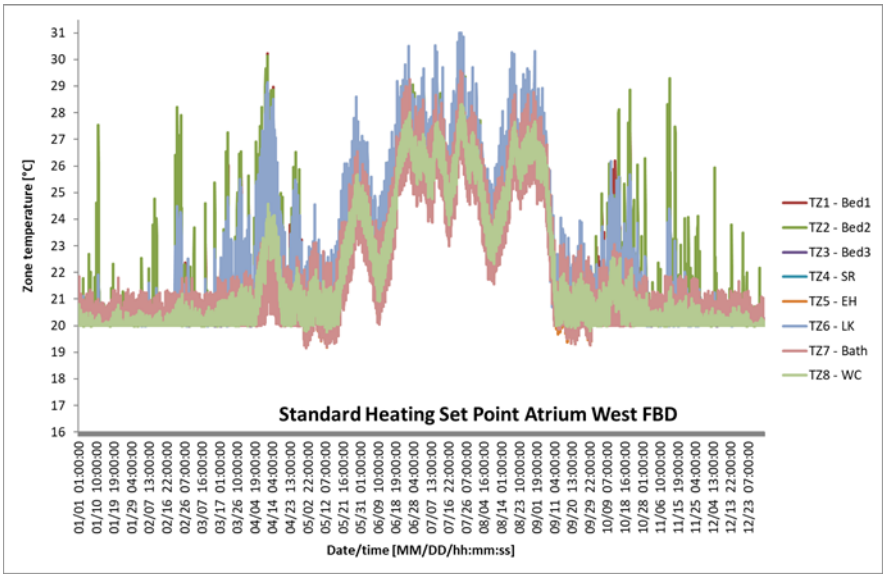

Figure 86: Indoor air temperatures for the standard HSP model of the Atrium West building FBD

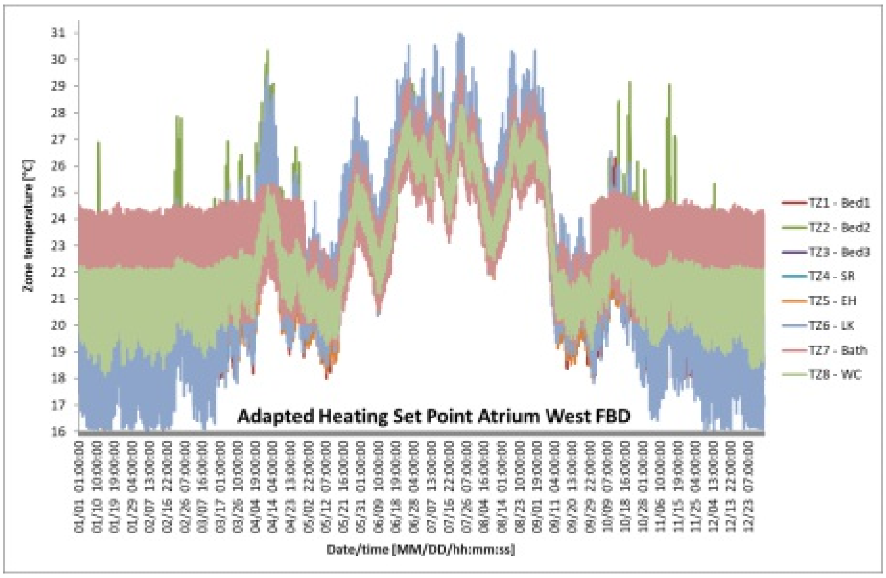

Figure 87: Indoor air temperatures for the adapted HSP model of the Atrium West building FBD

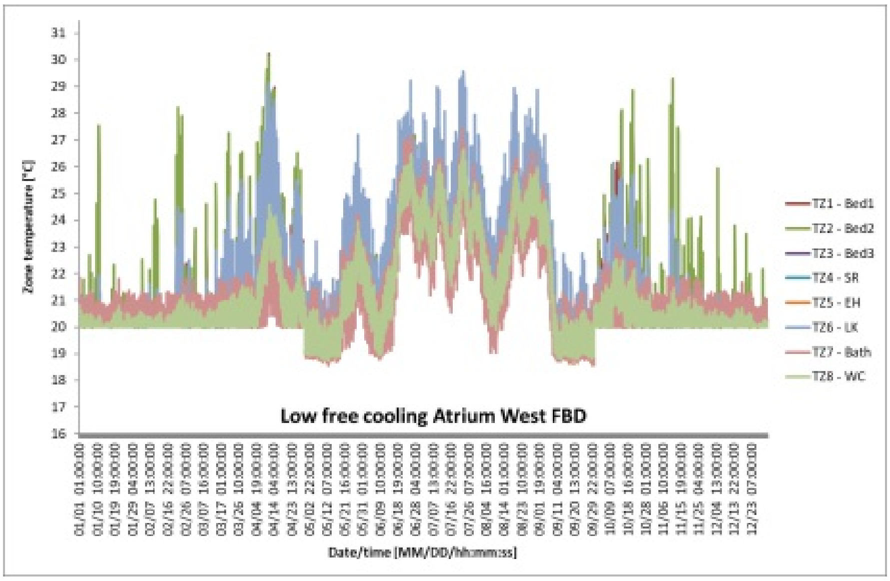

Figure 88: Indoor air temperatures for the low FC model of the Atrium West building FBD

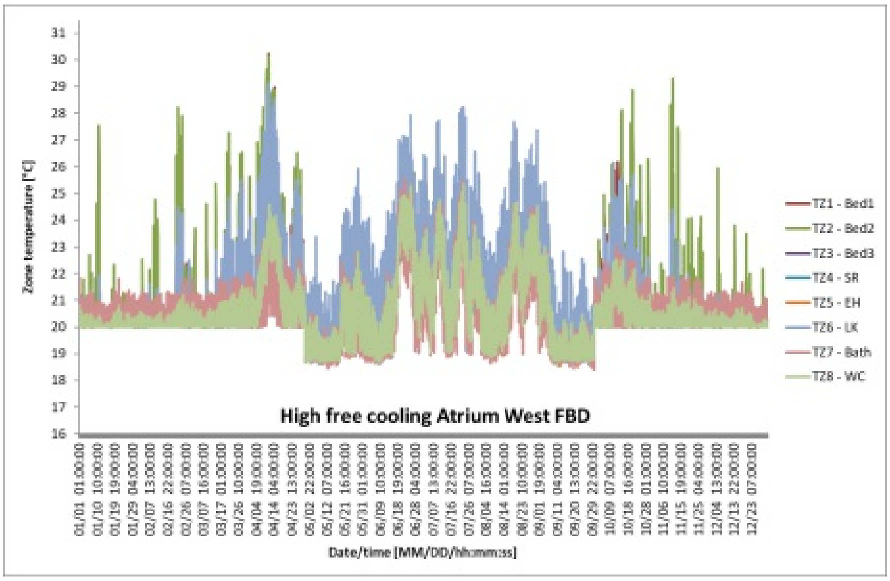

Figure 89: Indoor air temperatures for the high FC model of the Atrium West building FBD

Ventilation scenarios final building design compound

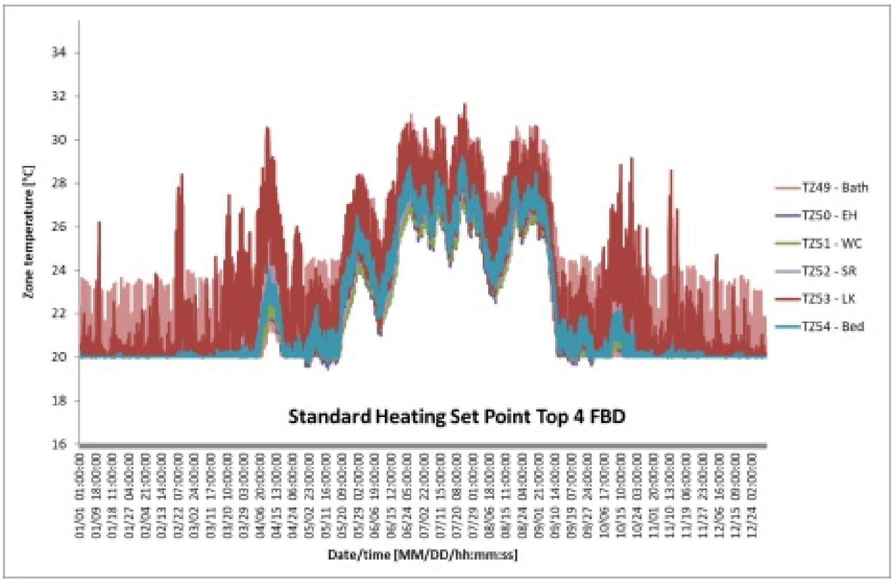

Figure 90: Indoor air temperatures for the standard HSP model of Top 4 FBD

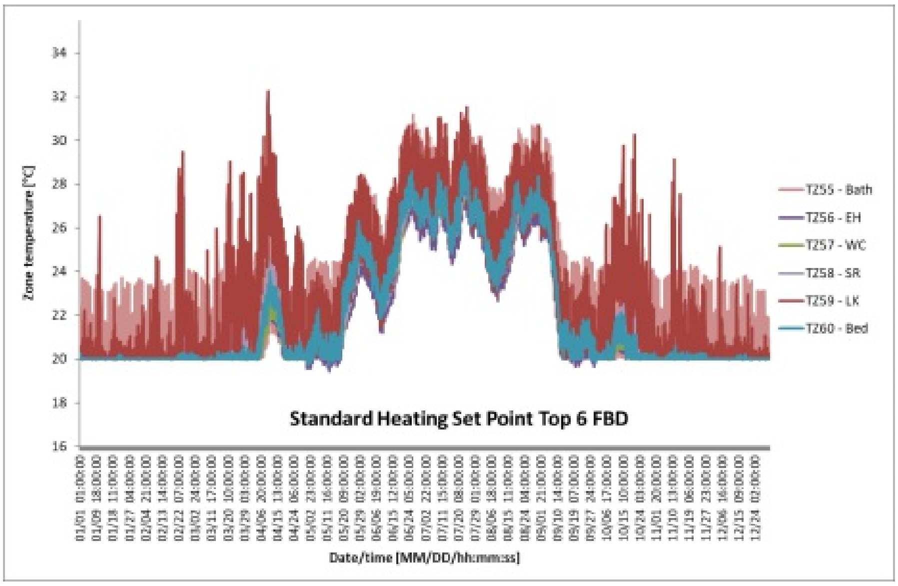

Figure 91: Indoor air temperatures for the standard HSP model of Top 6 FBD

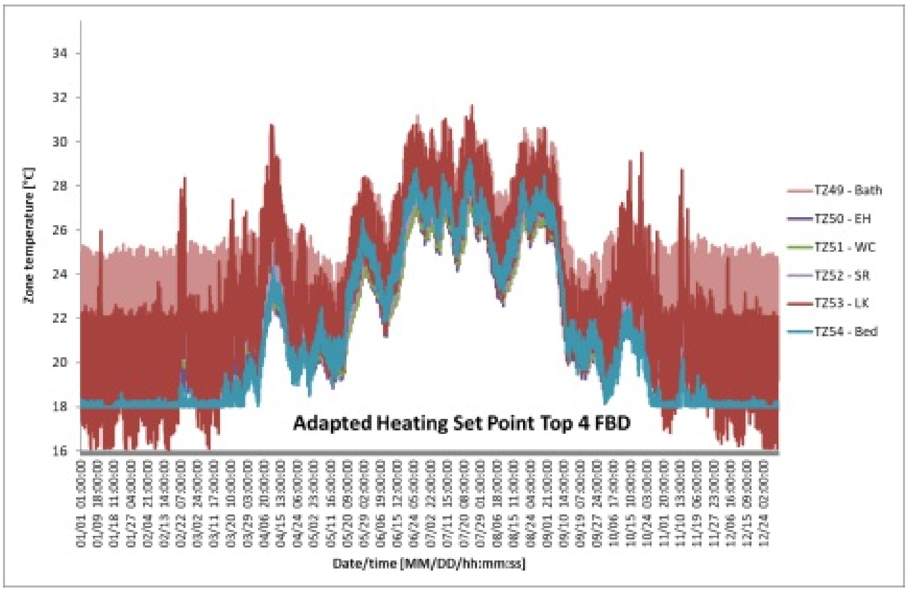

Figure 92: Indoor air temperatures for the adapted HSP model of Top 4 FBD

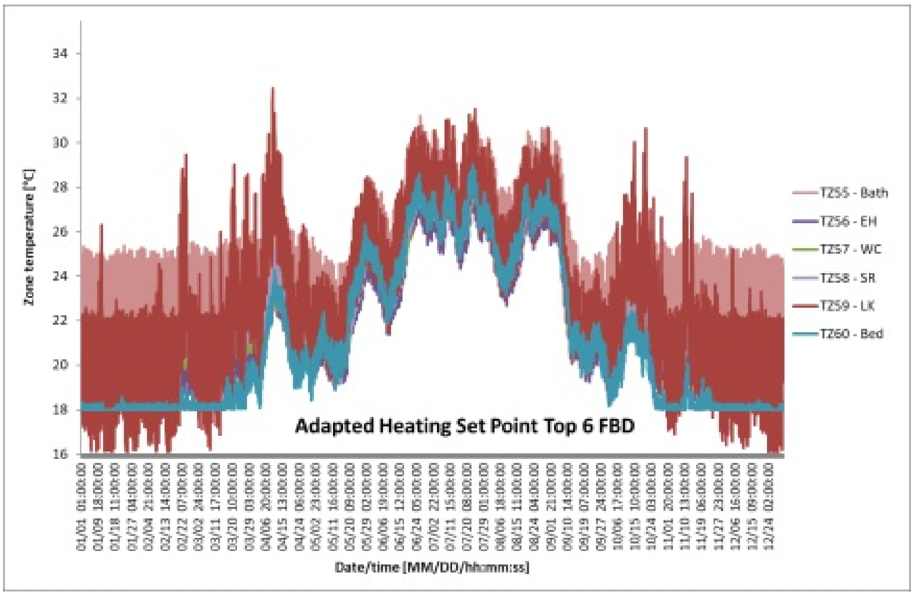

Figure 93: Indoor air temperatures for the adapted HSP model of Top 6 FBD

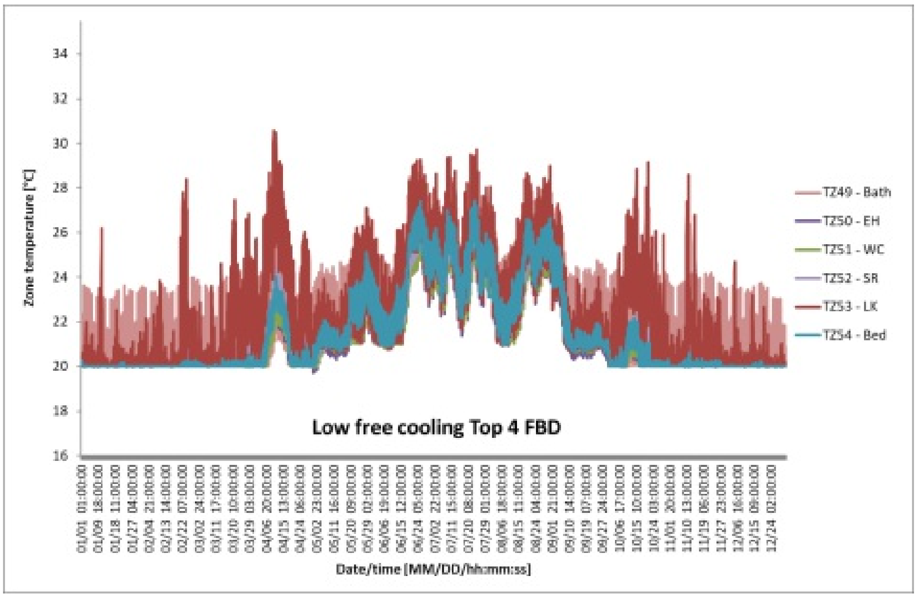

Figure 94: Indoor air temperatures for the low FC model of Top 4 FBD

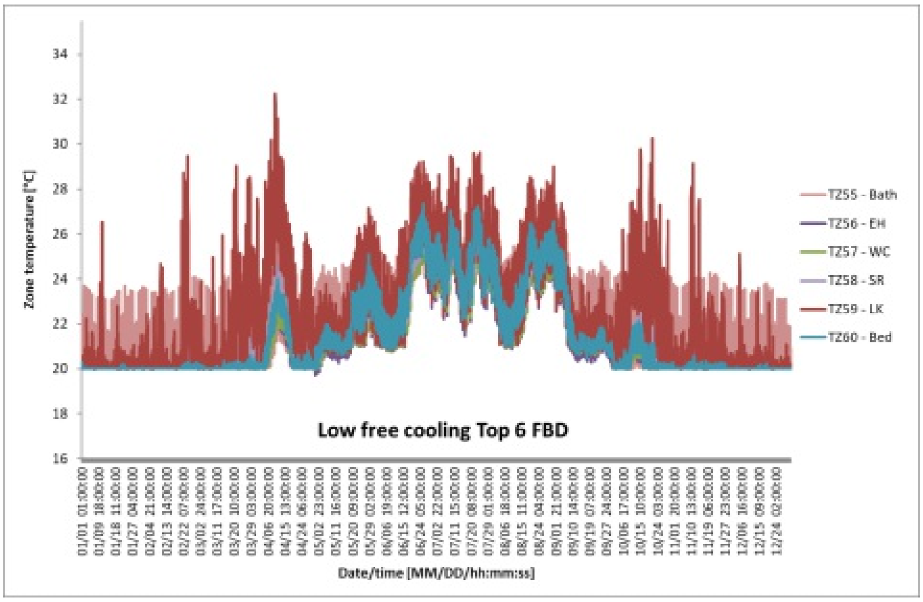

Figure 95: Indoor air temperatures for the low FC model of Top 6 FBD

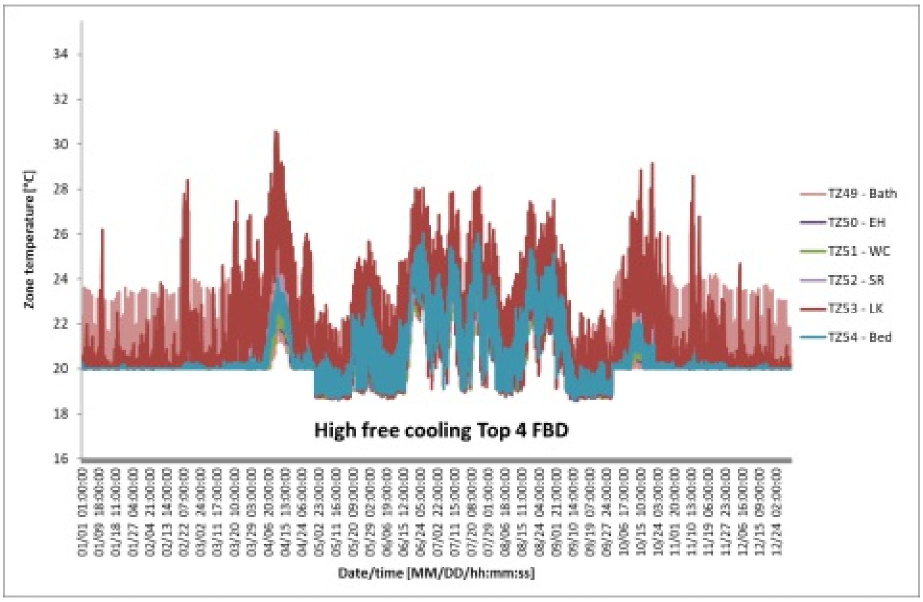

Figure 96: Indoor air temperatures for the high FC model of Top 4 FBD

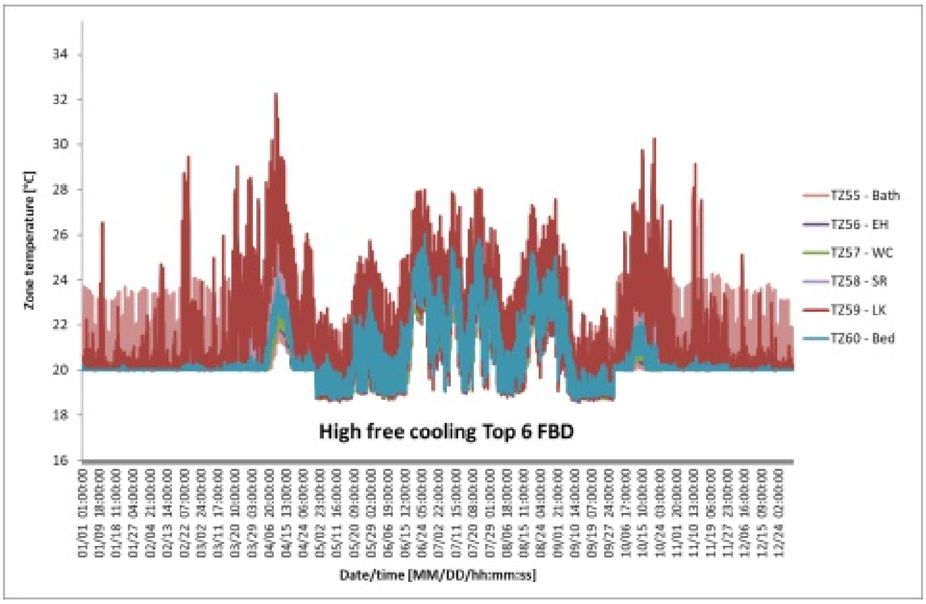

Figure 97: Indoor air temperatures for the high FC model of Top 6 FBD

Assessment of overheating risk for the detailed planning permit design

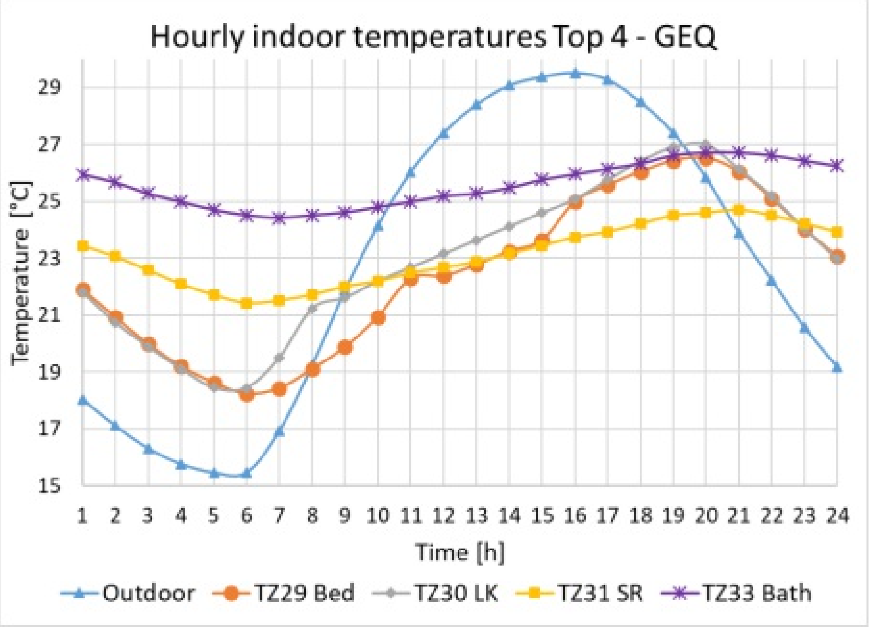

Figure 98: Indoor temperatures of Top 4 for GEQ

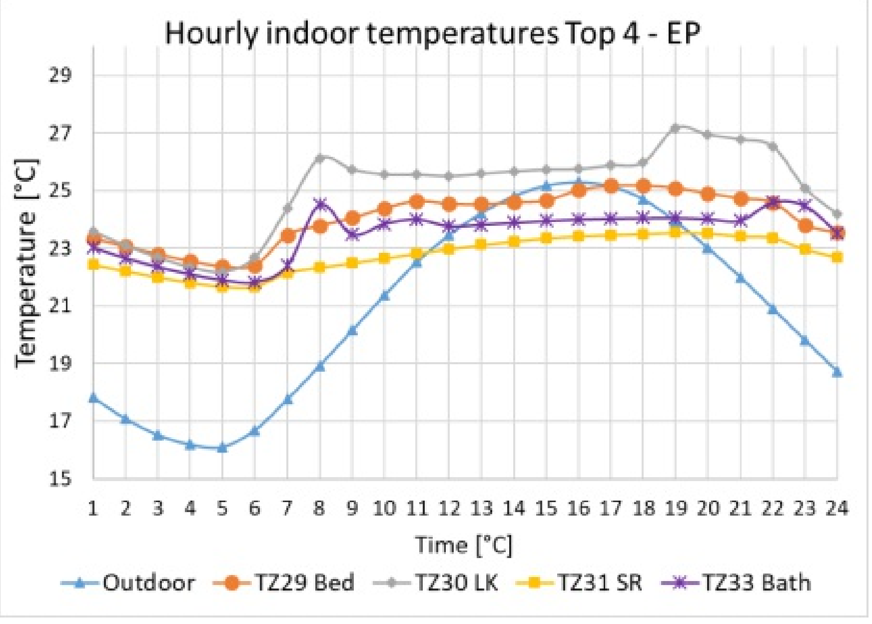

Figure 99: Indoor temperatures of Top 4 for EP+

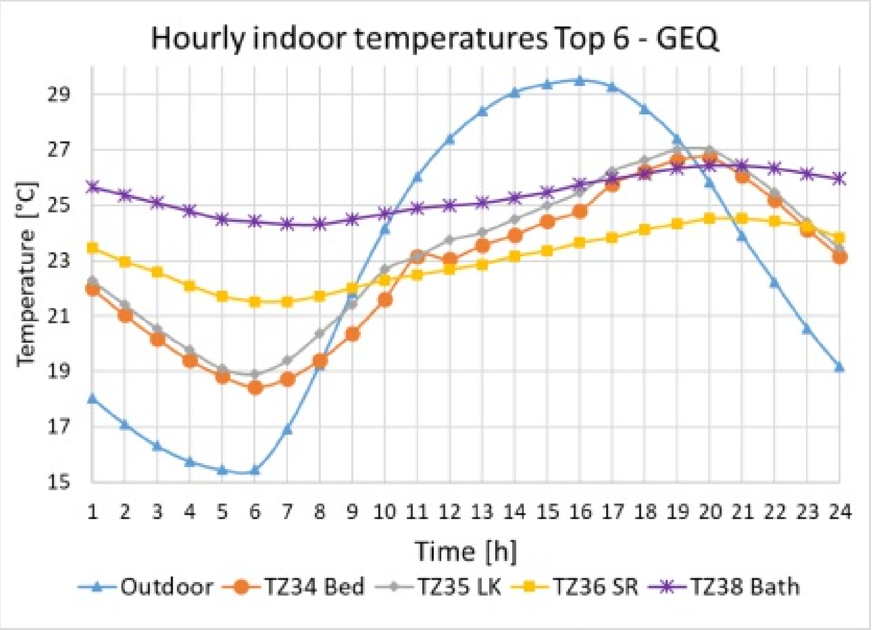

Figure 100: Indoor temperatures of Top 6 for GEQ

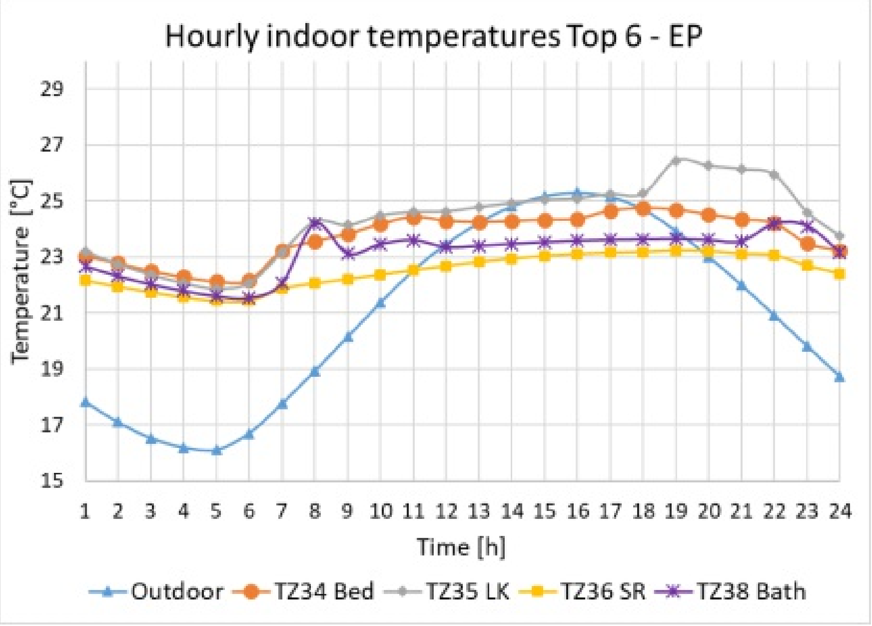

Figure 101: Indoor temperatures of Top 6 for EP+

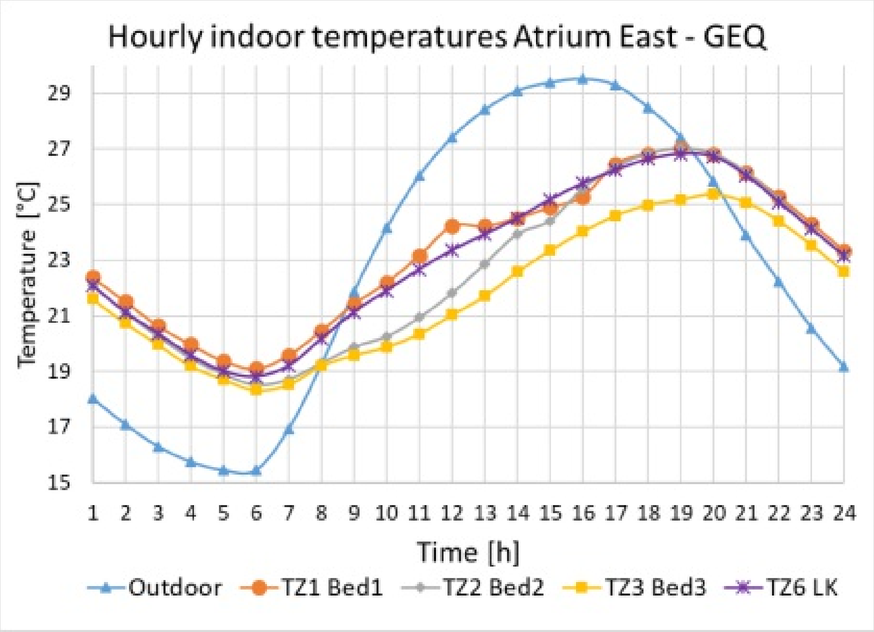

Figure 102: Indoor temperatures of Atrium East for GEQ

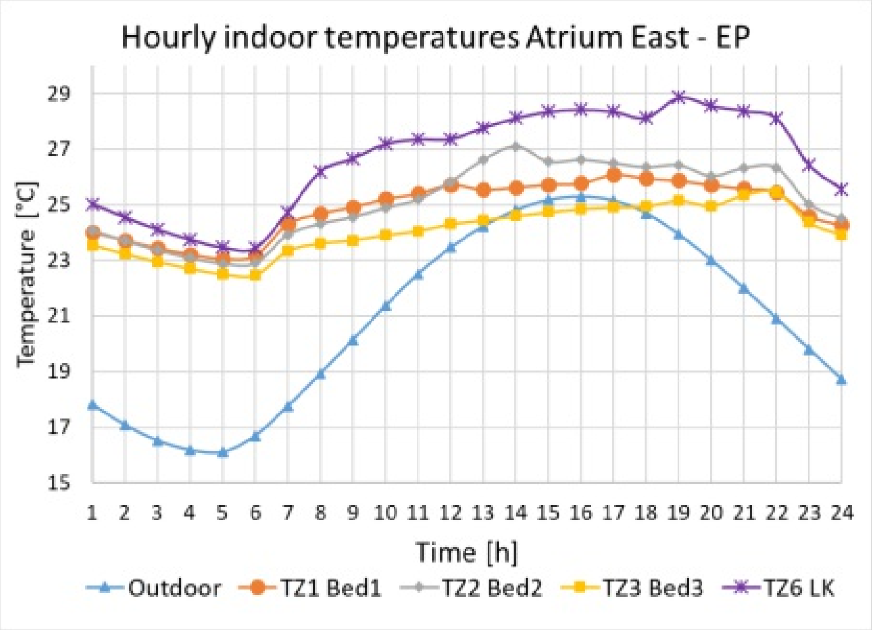

Figure 103: Indoor temperatures of Atrium East for EP+

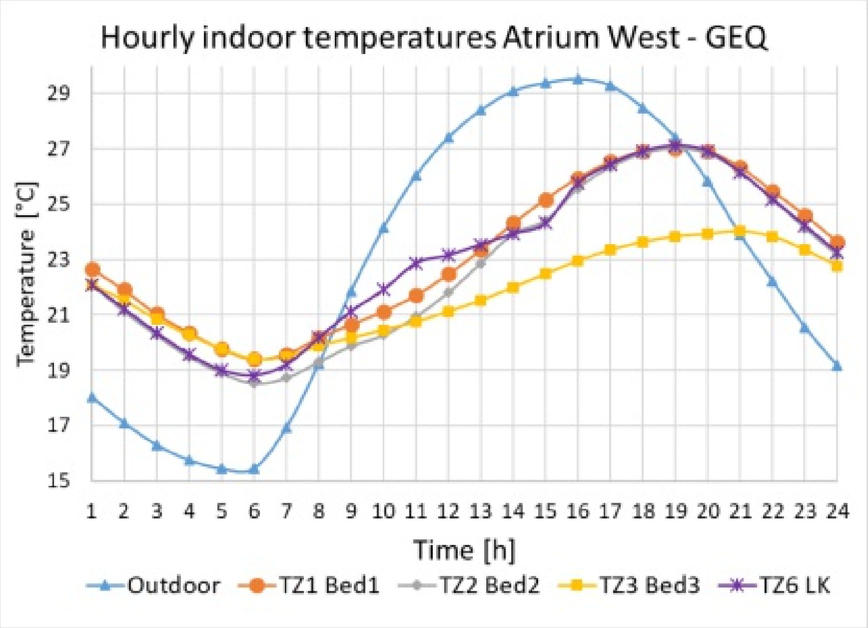

Figure 104: Indoor temperatures of Atrium West for GEQ

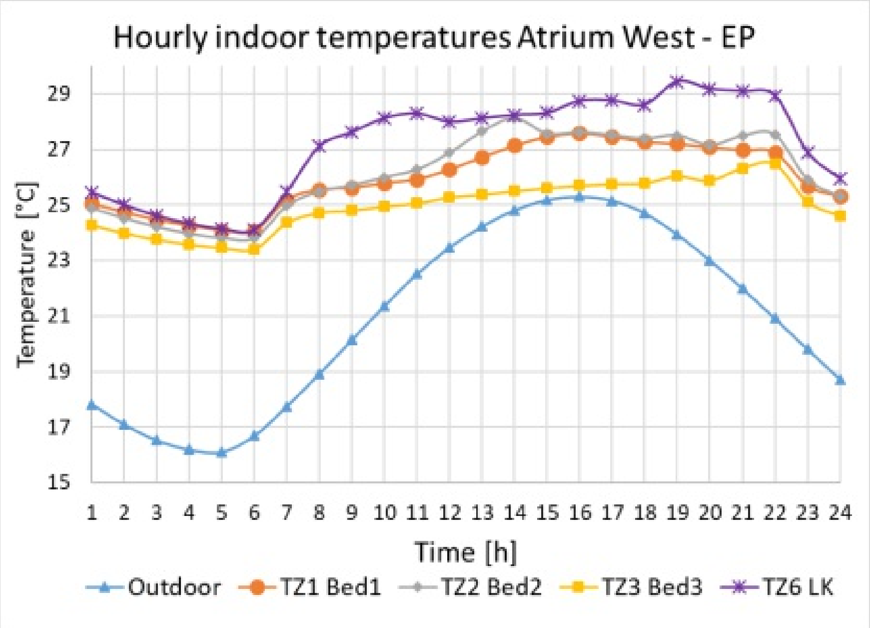

Figure 105: Indoor temperatures of Atrium West for EP+

Assessment of overheating risk for the final building design

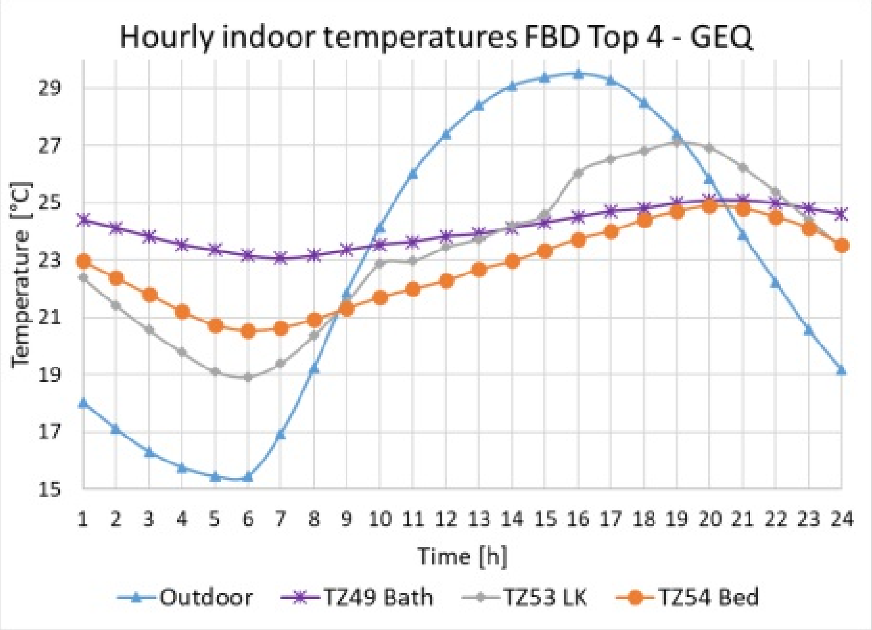

Figure 106: Indoor temperatures of FBD Top 4 for GEQ

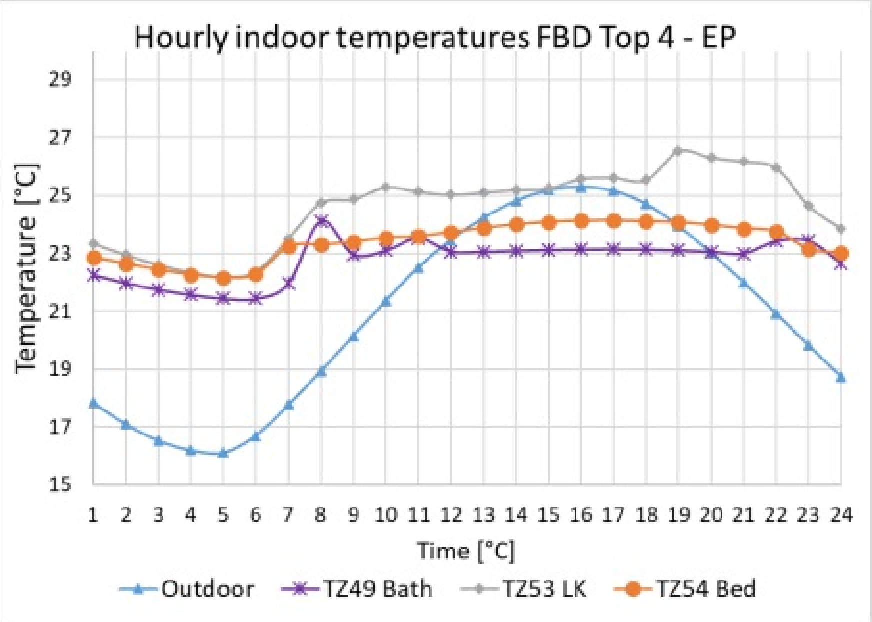

Figure 107: Indoor temperatures of FBD Top 4 for EP+

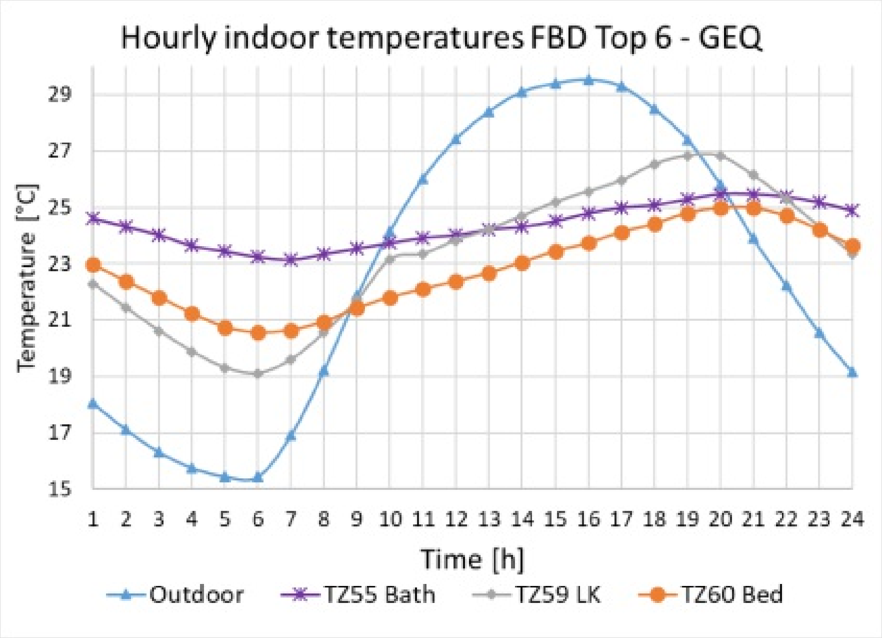

Figure 108: Indoor temperatures of FBD Top 6 for GEQ

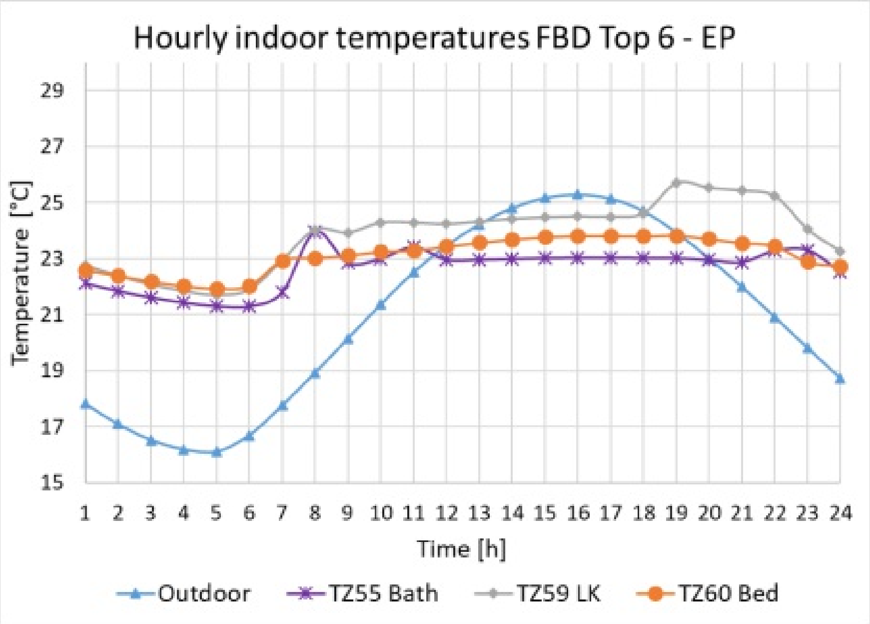

Figure 109: Indoor temperatures of FBD Top 6 for EP+

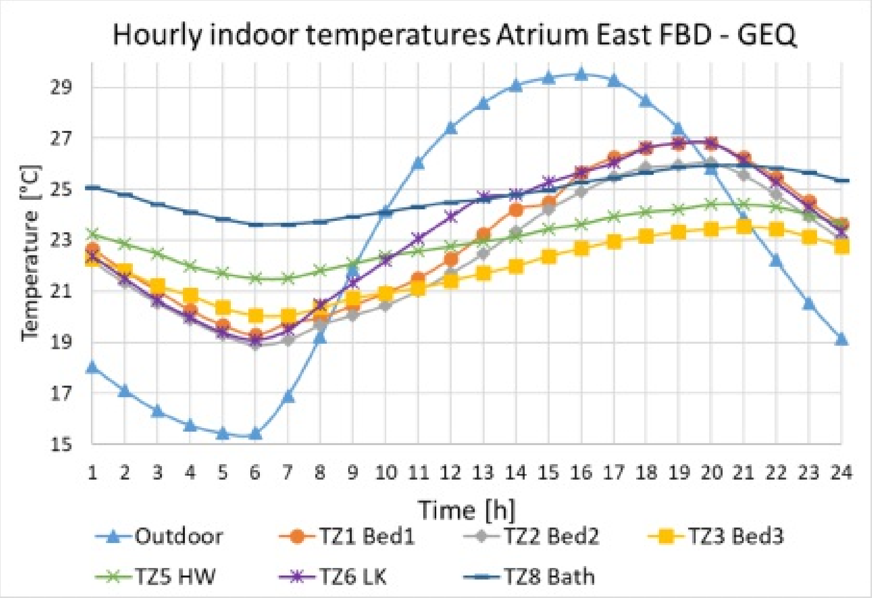

Figure 110: Indoor temperatures of Atrium East FBD for GEQ

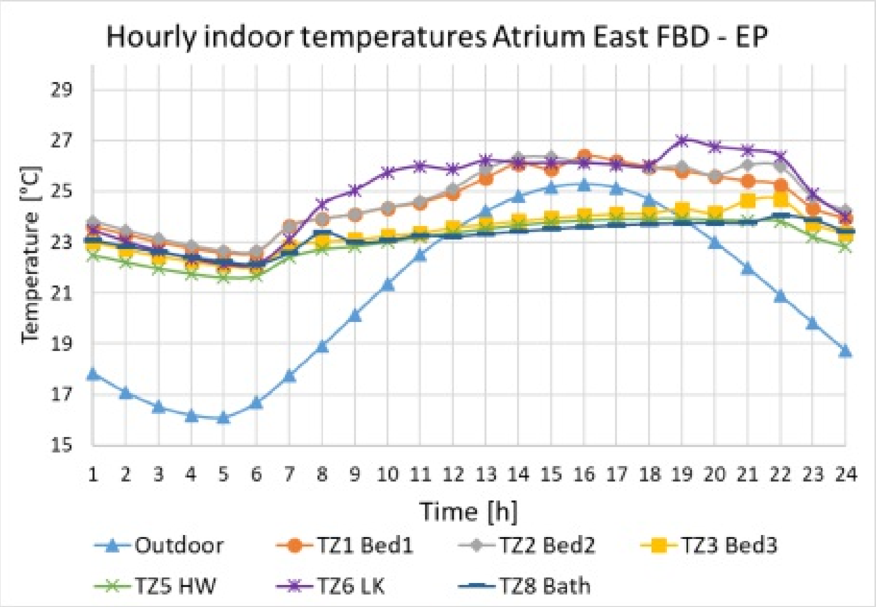

Figure 111: Indoor temperatures of Atrium East FBD for EP+

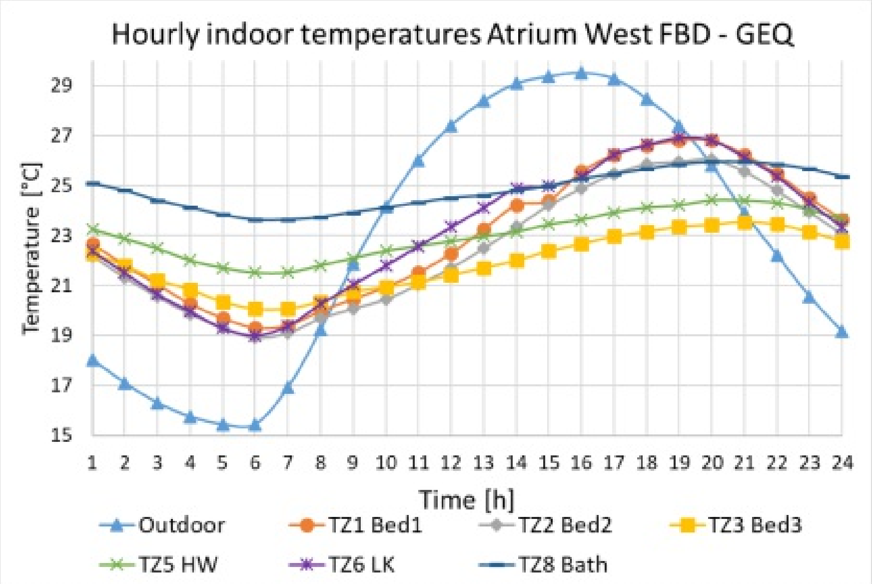

Figure 112: Indoor temperatures of Atrium West FBD for GEQ

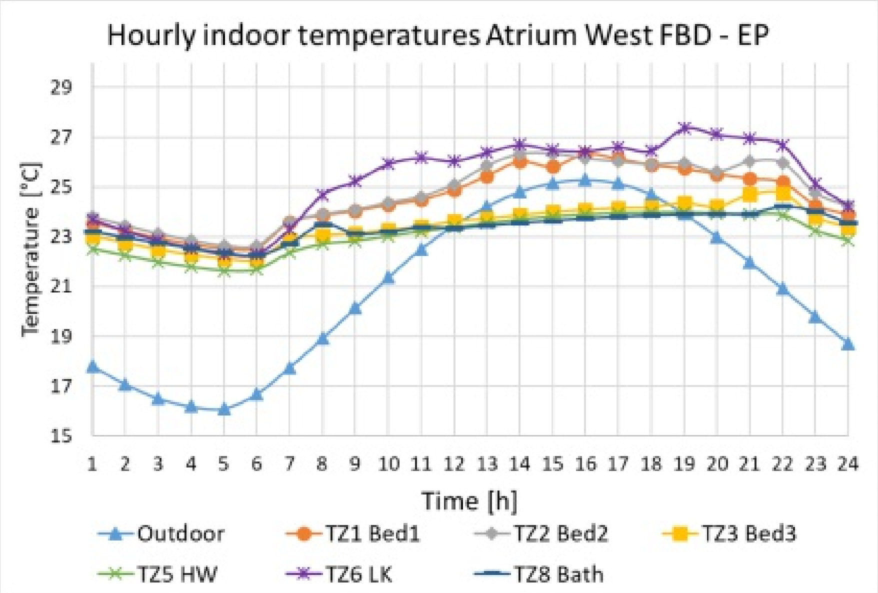

Figure 113: Indoor temperatures of Atrium West FBD for EP+

C. Curriculum Vitae

Name	DI DI(FH)Sören Eikemeier
Date of birth	28 November 1981
Place of birth	Hanover, Germany
Nationality	German

Professional background

Since 2009	**Center for Appropriate Technology, TU Vienna, Austria** Scientific assistant/researcher and project coordinator at the Center for Appropriate Technology at TU Vienna with the main topics: Renewable resources, ecological constructions and materials, life cycle analysis, building simulation, renewable energies
2016	**Research Executive Agency, European Commission** External Expert, Evaluation Team
2015	**Palawan Council for Sustainable Development, Puerto Princesa, Philippines** Research visit, as part of the KUWI scholarship of TU Vienna with the topic: Building monitoring in tropical climate
2014	**University of Applied Sciences Salzburg/Kuchl, Austria** Guest lecturer in winter semester 2013/2014 for: BA Smart Building - Energy-efficient building technology and sustainable building
2008	**Center for Appropriate Technology, TU Vienna, Austria** Internship, Product- und process optimization of construction materials made of renewable resources. Material testing of construction materials
2007	**Work and Travel, Australia and South East Asia**
2005 - 2006	**FUCHS Europe Schmierstoffe GmbH, Advance Development, Mannheim, Germany** Internship, Online sensor technology for engine- and industry oils
2005	**University of Applied Sciences Hanover, Faculty for Bioprocess Engineering, Germany** Assistant
2002 - 2003	**German Red Cross, Hanover, Germany** Social service
2000	**Installation of solar panels, IDER, Brazil** Development aid volunteer

Educational background

Since 2016	**Doctoral Programme in Technical Sciences, Vienna University of Technology, Department of Building Physics and Building Ecology, Austria** As part of the FFG scholarship programme Industry-related Dissertations in cooperation with the Center for Appropriate Technology

2018	**Universidad Politécnica de Madrid, giSCI, Spain** Study visit, as part of the ATHENS network within the European Communities SOCRATES programme
2017	**Istanbul Technical University, Faculty of Architecture, Turkey** Study visit, as part of the ATHENS network within the European Communities SOCRATES programme
2013 - 2016	**Master´s Programme, Vienna University of Technology, Department of Building Physics and Building Ecology, Austria** Major Subject: Building Science and Technology
2011	**Energy Adviser A-Course, St. Pölten, Austria**
2003 - 2009	**Diploma Programme, University of Applied Sciences Hanover, Faculty for Bioprocess Engineering, Germany** Major Subject: Technology of Renewable Resources
2002	**Abitur (A level), Leibniz-Schule, Hanover, Germany**

Books

2016	S. Eikemeier: *Monitoring of a Prototype Building in Tropical Climate - Thermal Comfort Evaluation*, Akademiker Verlag, Formal Science Series, ISBN: 978-3-639-88665-8, Germany, 2016

Publications in journals (selection)

2019	S. Eikemeier, R. Wimmer, A. Mahdavi: *Life-cycle oriented simulation-supported heating demand optimisation of buildings: An Austrian case study,* Sustainability in the built environment for climate change mitigation: SBE19 Thessaloniki, IOP Conf. Series: Earth and Environmental Science 410 (2020) 012027, DOI:10.1088/1755-1315/410/1/012027, Thessaloniki, Greece, 2019
2019	S. Eikemeier, R. Wimmer, A. Mahdavi: *Simulation-supported shading design optimisation for a multi-storey building with passive cooling*, 10th International Conference IAQVEC 2019: Indoor Air Quality, Ventilation and Energy Conservation in Buildings, Zero Energy Buildings: Design and Energy Modelling, IOP Conference Series: Materials Science and Engineering, Volume 609 (2019) 072009, DOI: https://doi.org/10.1088/1757-899X/609/7/072009, Bari, Italy, 2019
2019	S. Eikemeier, A. Mahdavi, R. Wimmer: *Simulation-Supported Early Stage Design Optimisation for a Case Study of Life Cycle Oriented Buildings*, Applied Mechanics and Materials, 12th enviBUILD - Buildings and Environment – From Research to Application, Volume 887, pp. 353-360, Trans Tech Publications, ISBN-13: 978-3-0357-1202-5, DOI: 10.4028/www.scientific.net/AMM.887.353, Switzerland, 2019
2018	S. Eikemeier, R. Wimmer, A. Mahdavi: *Simulation-Supported Design Optimization of Atrium Buildings with Passive Cooling in Austria*, Sustainability in Energy and Buildings 2018, Smart Innovation, Systems and Technologies Volume 131, pp. 21-31, Springer International Publishing, ISBN: 978-3-030-04292-9, eBook ISBN: 978-3-030-04293-6 DOI: 10.1007/978-3-030-04293-6, Switzerland, 2018

2017 S. Eikemeier, M. Schuß, R. Wimmer et al.: *Monitoring of a Prototypical Free-Running Building: A case study in a Hot-and-Humid Climate*, Applied Mechanics and Materials, Buildings and Environment – Energy Performance, Smart Materials and Buildings Volume 861, pp 392-400, Trans Tech Publications, ISBN: 978-3-0357-1070-0, DOI: 10.4028/www.scientific.net/AMM.861.392, Switzerland, 2017

2017 R. Wimmer, S. Eikemeier: *Angepasste Technologien für ein zukunftsfähiges Bauen*, OIB aktuell, Vol.4/2017, ISSN: 1615-9950, Austrian Institute of Construction Engineering, Vienna, Austria, 2017

2016 R. Wimmer, S. Eikemeier, A. Preisler, M. Berger: *Life Cycle Habitation – Designing Green Buildings*, Special Volume, SBE16 Tallinn and Helsinki Conference „Build Green and Renovate Deep“, Energy Procedia Volume 96 (2016), pp. 323-332, Elsevier, DOI: 10.1016/j.egypro.2016.09.155, Estonia and Finland, 2016

Publications in conference proceedings (selection)

2019 S. Eikemeier, R. Wimmer, A. Mahdavi: *Prevention of overheating risk: Assessment of a building project with lightweight construction in Austria*, Proceedings of the Conference (Abstracts), International Conference enviBUILD 2019 - Buildings and Environment, ISBN 978-80-227-4959-6, Slovak University of Technology, Slovakia, 2019

2016 S. Eikemeier, M. Schuß, R. Wimmer et al.: *Monitoring of a Prototypical Free-Running Building: A case study in a Hot-and-Humid Climate*, Proceedings of the Conference (Abstracts), International Conference enviBUILD 2016 - Buildings and Environment, ISBN 978-80-214-5392-0, Brno University of Technology, Czech Republic, 2016

2016 S. Eikemeier, R. Wimmer: *Performance of the ZCR passive cooling design - Thermal comfort in the Philippines*, Proceedings of the Conference, 2nd international Zero Carbon Building Conference 2016 - Zero Carbon Buildings Today and in the Future, Birmingham City University, ISBN: 978-1-904839-88-0, Birmingham, UK, 2016

2016 S. Eikemeier: *Life Cycle Habitation – Lebenszyklusorientierte Gebäude*, Proceedings of the Conference, Symposium: 30 Jahre „Angepasste Technologie - Eine Erfolgsgeschichte”, Vienna University of Technology, Vienna, Austria, 2016

2014 S. Eikemeier, R. Wimmer: *Life Cycle Habitation – zero carbon building concepts*, Proceedings of the Conference, 1st international Zero Carbon Building Conference 2014 - Zero Carbon Buildings Today and in the Future, Birmingham City University, Birmingham, UK, 2014

2013 R. Wimmer, S. Eikemeier: *Zero Carbon Village – Energy self-sufficiency, Modular Prefabrication and Sustainable Building Materials*, Proceedings of the Conference, Sustainable Building 2013. Graz, Austria, 2013

2013 S. Eikemeier, R. Wimmer: *Zero Carbon Village – Strategien für ein CO_2-neutrales Bauen und Wohnen*, Bauz! – IBO Kongress, Vienna, Austria, 2013

2012 S. Eikemeier, R. Wimmer, M. Burghardt: *Zero Carbon Village – CO_2-neutral bauen und wohnen*, Proceedings of the Conference, *Nachhaltige*

Gebäude, E-NOVA - internationaler Kongress, Pinkafeld, Austria, 2012

2009 R. Wimmer, R. Bintinger, S. Eikemeier*: Strohballen - auf dem Weg zu einem zertifizierten Baustoff,* Alpen-Adria Passivhaustagung, Pécs, Hungary, 2009

Scientific reports, publicated final reports (selection)

2016 R. Wimmer, S. Eikemeier: *Zero Carbon Gebäude International - Begleitmessung und Auswertung*, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, Austria, 2017

2014 R. Wimmer, M.J. Kang, S. Eikemeier: *Green Building Austria – Kooperationen und Marktaufbereitung im asiatischen Raum*, Österreichische Forschungsförderungsgesellschafft mbH, Vienna, Austria, 2014

2012 R. Wimmer, S. Eikemeier, M. Burghardt et al.: *Zero Carbon Village Energieautarke Siedlung, Industrielle Forschung*, Haus der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, Austria, 2012

2012 R. Bointner, R. Haas, T. Bednar, S. Eikemeier et al.: *Gebäude maximaler Energieeffizienz mit integrierter erneuerbarer Energieerschließung,* Haus der Zukunft plus, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, Austria, 2012

2010 R. Wimmer, H. Hohensinner, S. Eikemeier, R. Bintinger, S. Prokupek: *Entwicklung eines baubiologisch hochwertigen Wärmedämmverbundsystems auf Basis von Schilf*, Fabrik der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, Austria, 2010

Diploma and Master Thesis

2016 S. Eikemeier: *Monitoring and Evaluation of a Prototype Building in Tropical Climate regarding Thermal Comfort*, Master Thesis, Vienna University of Technology, Vienna, Austria, 2016

2009 S. Eikemeier: *Entwicklung eines Wärmedämm-Verbundsystems aus dem nachwachsenden Rohstoff Schilf mit anschließender Prüfung der bauphysikalischen Anforderungen für eine Zertifizierung auf europäischer Ebene*, Diploma Thesis, University of Applied Science Hanover, Hanover, Germany, 2009

Conferences, trainings, workshops, presentations, competitions (selection)

2019 Speaker, International Conference: *"SBE19 - Sustainability in the built environment for climate change mitigation",* Thessaloniki, Greece, 23-25 October 2019

2019 Speaker, International Conference: *"IAQVEC 2019: Indoor Air Quality, Ventilation and Energy Conservation in Buildings",* Bari, Italy, 05-07 September 2019

2018 Speaker, International Conference: *"Sustainability in Energy and*

	Buildings – SEB18", Gold Coast, Queensland, Australia, 24-26 June 2018
2017	Speaker, International Conference: *"enviBUILD 2017 – Buildings and Environment"*, Vienna University of Technology, Vienna, Austria, 07-08 September 2017
2016	Speaker, Sustainable Built Environment Conference: *"Build Green and Renovate Deep"* – SBE16, Tallinn and Helsinki, Estonia und Finland, 05-07 October 2016
2016	Scientific Committee Member and Speaker, International Conference: *"enviBUILD 2016 – Buildings and Environment"*, Brno University of Technology, Brno, Czech Republic, 22-23 September 2016
2016	Scientific Committee Member, International Conference: *"Zero Carbon Buildings Today and in the Future 2016"* – 2nd ZCB Conference, Birmingham City University, Birmingham, UK, 8-9 September 2016
2015	Lecturer, Zero Carbon Resorts Training Course: *"Replace and Redesign"*, PCSD Training Institute, Irawan, Puerto Princesa, Philippines, 20-25 April 2015
2014	Scientific Committee Member and Chair, International Conference: *"Zero Carbon Buildings Today and in the Future 2014"* - 1st ZCB2014, Birmingham City University, Birmingham, UK, 11-12 September 2014
2014	Keynote Speaker, European Conference: *"Renaturing Cities: Addressing Environmental Challenges and the Effects of the Economic Crisis through Nature-based Solutions"*, Auditorium Madou, Brussels, Belgium, 13-14 May 2014
2013	*Solar Decathlon,* Competition by the U.S. Department of Energy, Team Austria, California, United States, 2013 (first place)
2011	Keynote Speaker, Dialog Holzbau 2011: *"Nachhaltiges Bauen – Die Rückkehr der Naturbaustoffe"*, Wirtschaftskammer Oberösterreich, Linz, Austria, 16 May 2011