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DIPLOMARBEIT

A Comparison of the Thermal Performance of a New Building with a Thermally Retrofitted Residential Housing Unit – Case Study

Ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Diplom-Ingenieur

unter der Leitung von

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ZUSAMMENFASSUNG

Diese Diplomarbeit befasst sich mit dem Vergleich von Energieersparnissen, Reduzierung von Treibhausgasen und Finanzierungsoptionen von Kleinfamilien-Wohnhäusern anhand von zwei benachbarten Gebäuden im Burgenland, Österreich. Die Fallbeispiele, ein Haus errichtet in den 50er Jahren und ein Neubau aus 2014, werden in folgenden Bereichen verglichen und analyisiert: (1) Verbesserung der thermischen Leistung, (2) Verbesserung des ökologischen Fußabdrucks und (3) Verbesserung der Energieeffizienz der folgenden 30 Jahre. Eine Simulation des alten Gebäudes in einer renovierten Form wird den Ergebnissen des Neubaus gegenüber gestellt. Das Resultat dieser Studie wird die Wirkung einer Sanierung eines Altbaus im Vergleich darstellen.

Stichwörter

Altbausanierung, Energieersparnisse, Rentabilität, Wirtschaftlichkeit, thermische Leistung

ABSTRACT

The objective of this study is to compare the energy savings, decrease in greenhouse gases and economic benefits of housing units on the basis of two neighbouring houses in Burgenland, Austria. In this study a residential house built in the early 1950s and another unit constructed in 2014 will be compared and analysed with emphasis on: (1) improvement of thermal performance, (2) improvement in eco footprint and (3) improvement of energy efficiency over a period of 30 years. A simulation of a renovated model of the old house will be created to contrast the values of a restored building towards a newly constructed unit. The outcome of this study will empirically show the effects of renovating old buildings to low-energy standards.

Keywords

Thermal Retrofit, Energy-saving, Feasibility, Economic aspect, Thermal performance

CONTENTS

Chapter 1

Introduction

1.1 Overview

An ongoing topic in the field of building performance is the current quality and duration of renovations of buildings in Europe. Although the goals, proposed by the European Commission in March 2010, for the energy strategy *Europe 2020* suggests that by 2020 greenhouse gas emissions should have decreased by 20 % lower than 1990 by increasing the renovation rate of buildings to 3 % (European Commission, 2010), it is adviced to change the goal from annual 3 % standard renovations to 80 % renovations to low energy standard by 2020. This study shows that an immediate increase before 2020 has a greater long term impact on energy savings by 2050 (Müller, 2011). No doubt that these goals will lower the heating demand by insulating old buildings. However, latest studies in Germany have shown that the costs of renovation are more than double as high as the actual energy costs saved (KfW-Studie, 2013).

The following study will compare different aspects of two neighbouring residential houses as they currently are. One house has been built in the early 1950s and was extended in the late 80s. Both parts have either underperforming or no insulation and show bad thermal properties overall. The other house is operational since 2014. It is a modern house with a geothermal heat pump, heat exchanging systems and will fulfil low energy standards. Second, the properties of the houses will be compared to each other after the older building has been remodelled and simulated with low energy standards. It will be interesting to see how the thermal energy and ecological performances of the old house have improved and whether it can compete with the standards of newly built buildings. A cost estimation of the renovation will be faced with the heating costs saved, the amortization time of the renovation will be calculated and again compared the results to the new building.

1.2 Motivation

In the last decades, the rate of renovating old buildings has shown a steady growth in the construction sector. In Austria retrofitting is encouraged and supported by the government with 30 million euros for businesses and 70 million euros for private entities (WKO, 2013). Studies about thermal retrofits and performances usually have their focus on multi-story buildings in bigger cities and capitals. On contrary, the following case study will be covering buildings on the country side afar from urbanity, looking at one-family residential housing units. The outcome of this thesis will show whether within 30 years it is more beneficial to renovate or build a house in a rural area.

1.3 Background

The location of the buildings in question is a small village called Unterwart. It is part of Oberwart, which is one of the nine municipalities of Burgenland in Austria. As most regions in Burgenland have a positive migration balance, Oberwart is no exception with 193 new residents moving in (Statistik Burgenland, 2012). Unterwart is located in the south of Burgenland and with an approximate distance of 10 km to the Hungarian border, which is the reason why this village is one of the few communities with bilingual education and local signs.

During the last two centuries this area was focused on heavy agriculture and foresting due to the geographic advantages and the river Pinka running through this province. After the World War II starting in the second half of the last century, the interest of the new generations in continuing the farms and barns of their ancestors diminished. This led to today’s current situations of empty unused farm houses or excessively huge storage spaces. These blank rooms will be reactivated in this thesis and it will be seen if they can be as attractive as a newly built space.

Chapter 2

Method

2.1 Overview

The following chapter describes the scientific method of the work. The main objectives are two residential houses in Unterwart, Burgenland. The comparison of the two case studies is divided in three categories: (1) thermal performances, (2) environmental factors and (3) financial costs, of the next 30 years.

2.1.1 Data Acquisition

The first step of the thesis is to acquire all the relevant information for the simulations and calculations. After a site inspection and documentation, updated plans of both projects are drawn. By communicating with the owners and the architect of the houses, a list of all the building components is created in a database. To complete the database, online research for physical attributes, environmental impact and costs for materials and heat demand is conducted.

2.1.2 Software Tools

For this thesis many different CAD and simulation tools are used. 2D- and 3D-models are drawn in Graphisoft Archicad 17 (2014) and Google Sketchup 2013 (2014). Energy certificates are created in ArchiPhysik 11 (2014), whereas the thermal simulations are prepared in OpenStudio 1.3 (2014) and EnergyPlus 8.1 (2014). The database, graphs and calculations are done in MS Excel 2010 (2014) and Matlab 7.11.0 (2014).

2.2 Case Studies

The simulations and calculations are based on two buildings in Unterwart, Burgenland at 47°16'N 16°14'E and are located approximately 130 km south of Vienna, the capital of Austria (Figure 1). The sites of the case studies are next two each other and therefore share the same weather conditions (Figure 2).

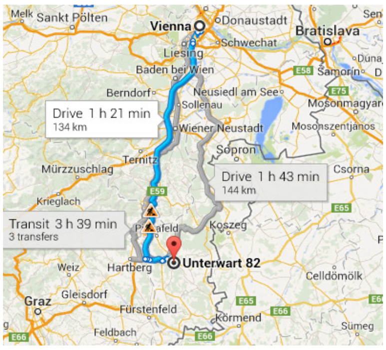


Figure 1, map of Unterwart
source: maps.google.com

Figure 2, case studies in Unterwart
source: maps.google.com

2.2.1 House 1950

The older building of the two in question was erected after World War II in the late 1950s by the parents of the current owners. During the course of this research, this building is referred to as 'House 1950'. It has been extended several times to benefit its function as a barn house. Although the gross area is about 300 m², the total liveable space currently amounts to 119 m² (Figure 3).

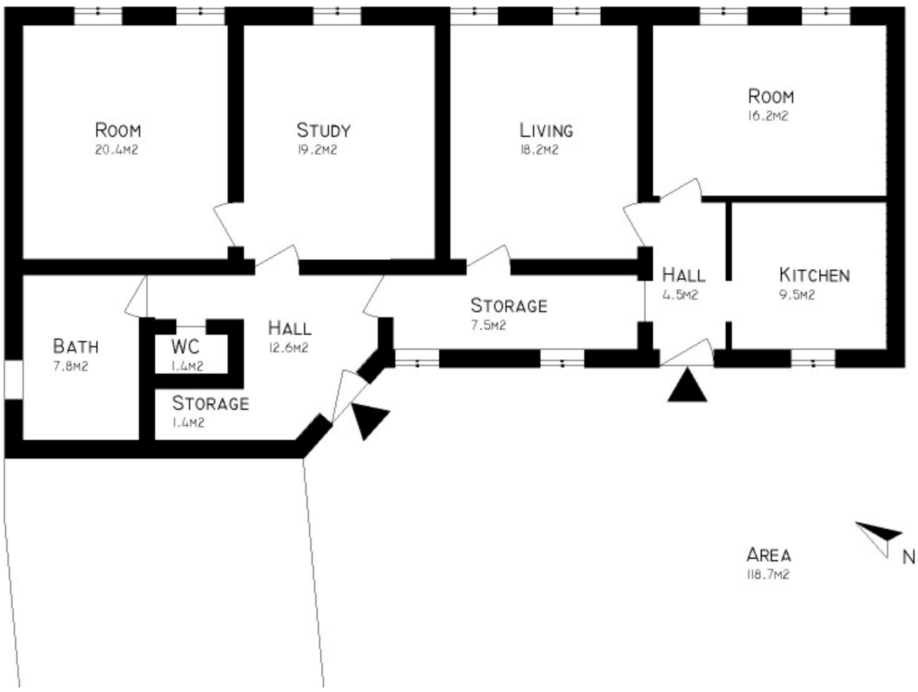


Figure 3, floor plan of House 1950, designed by the author

The exterior walls are made of bricks, common for the time and region. The windows to the main road are box-typed. Currently neither roof nor walls are insulated and the windows have never been replaced. There are two bed rooms, whereas the living room also acts as another bedroom, a study, a kitchen, a bath and a toilet. The old barn house is used as storage space.

2.2.2 House 2014

The second building in question is a newly built house. The construction started in early 2013 and it is operational since the end of 2014. This building will be referred to as 'House 2014'. It is a two story building with double the area of House 1950 (Figure 4). There are four bedrooms, two living areas, a study, a kitchen, two baths, three toilets, a garage and two roof terraces.

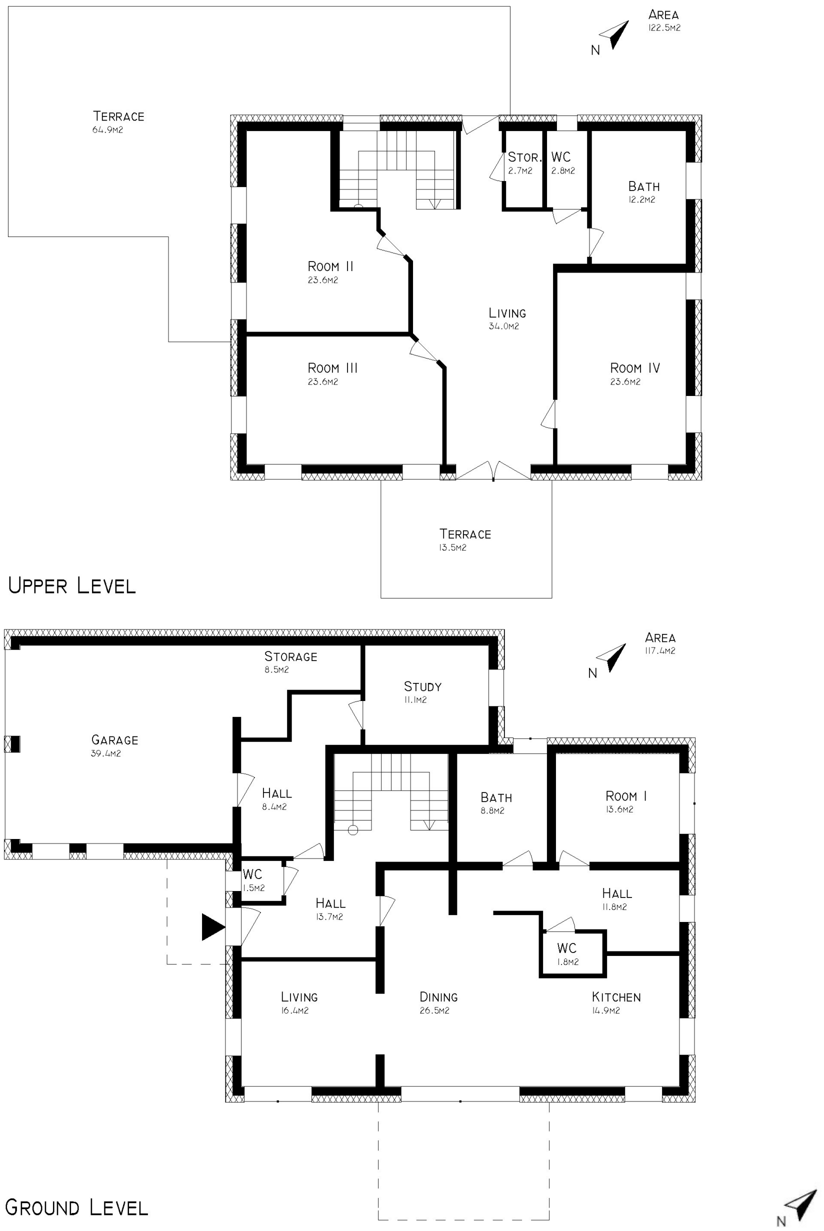


Figure 4, floor plan of House 2014 – ground and upper level, designed by the author

2.2.3 House 1950+

In order to compare the two projects, for this thesis House 1950 is renovated and an extension is designed in the existing part of the old barn (Figure 5). This unit will be referred to as House 1950+. It received a southwest extension of four new rooms and now has four bedrooms, a living room, a study, a kitchen, two baths and two toilets. The old rooms are remodelled and have partly new functions. The northeast part of the building could be used as a separate home office with the kitchen adjacent to the office room. The complete plans, sections and elevations of these buildings can be found in the appendix.

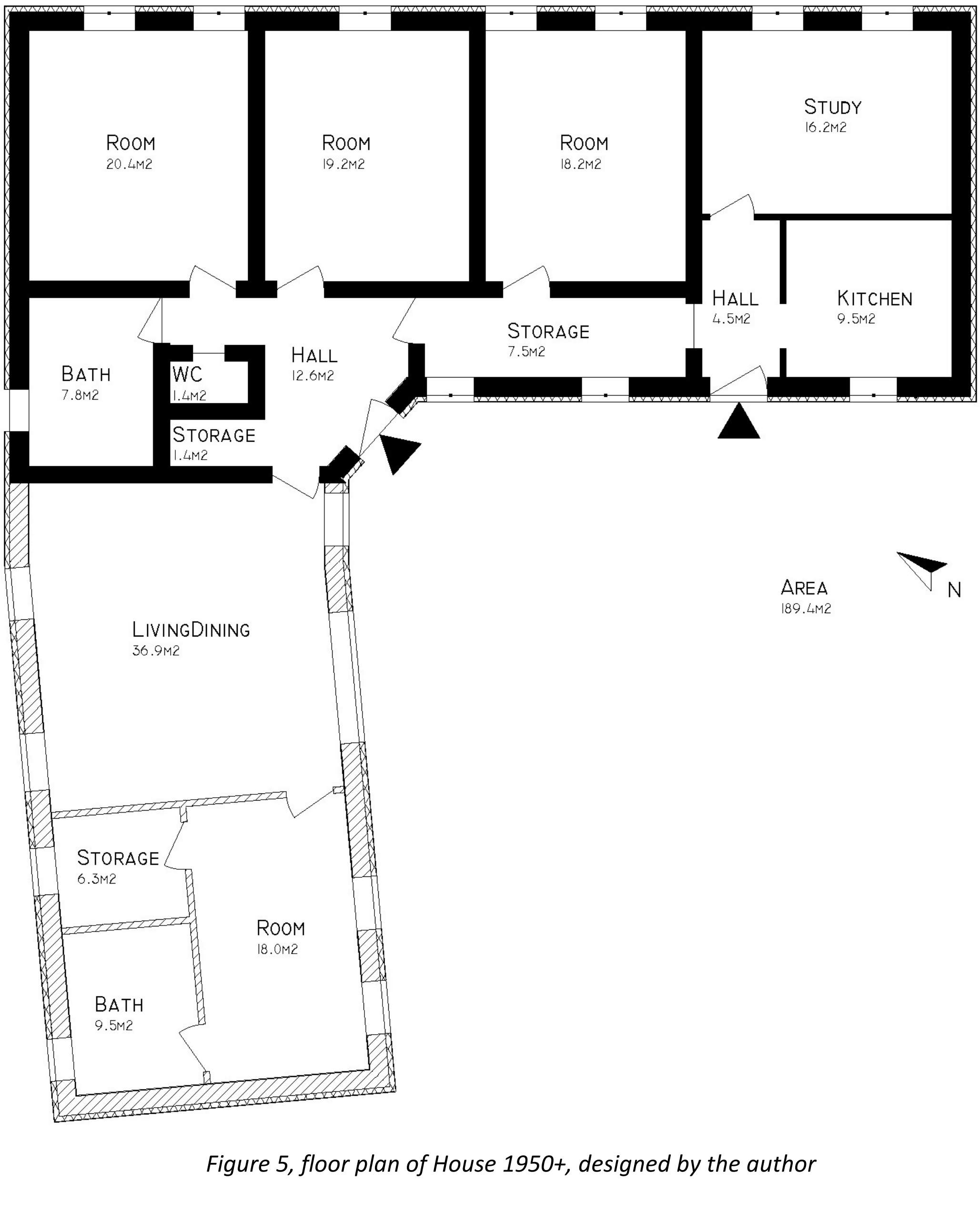


Figure 5, floor plan of House 1950+, designed by the author

2.3 Six Scenarios

In order to compare the projects, six different scenarios are going to be conducted in all the simulations and calculations. The first scenario is the model of House 1950, untouched as it is. The existing old building materials will be used in this scenario. The second scenario is based on the first model, but with improvements. The building elements will fulfil current thermal standards, by exchanging the old box-typed windows and adding insulation to the external walls and the attic. This scenario is divided into two different retrofit variations, which will be referred to as scenario 2.1 and 2.2. In the first variation the ceiling to the attic is insulated, but the roof remains the same. In the second variation it is the opposite as illustrated in Figure 6. After simulation and calculation these three scenarios will be compared. This shows how much the heating demand can decrease with proper insulation.

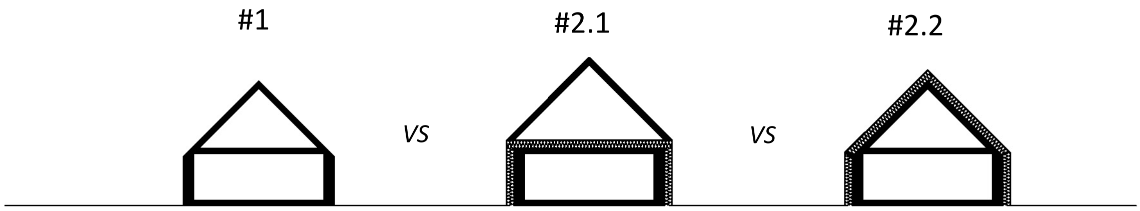


Figure 6, schemes of scenario #1 vs scenario #2.1 vs scenario #2.2

The third scenario is House 1950+. It is House 1950 after a retrofit and an additional extension. Like before, this retrofit is again divided into two variations: 3.1 and 3.2. These scenarios will be compared to the last scenario, which is House 2014 (Figure 7). The comparison of the final scenarios will show whether it is more beneficial to renovate a building or to build a new one instead.

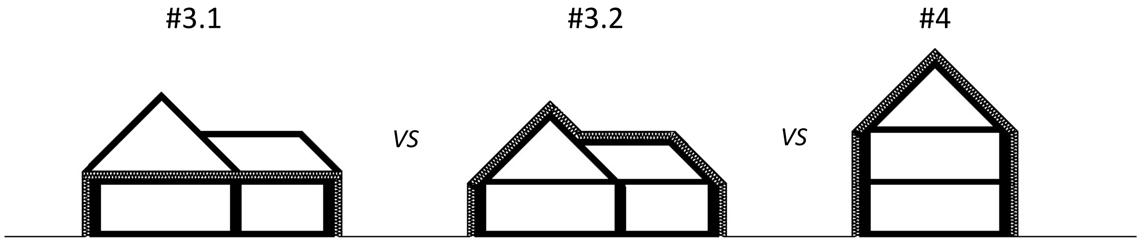


Figure 7, schemes of scenario #3.1 vs scenario #3.2 vs scenario #4

2.4 Statistical Analysis

For the simulations and calculations information about occupancies, activity levels and building components are necessary. These parameters are acquired from the current situation: how many occupants are living there at the moment and what materials are used in the buildings. For any missing information, assumptions based on regulations, standards or reference projects are made.

2.4.1 Occupancy

House 1950 was built and is owned by family Wallner. The household consists of five members: the parents and three children. In House 1950 two of the children share one bed room and the living room acts as another bedroom for the third child.

In House 1950+ and House 2014 every child has its own bedroom. The living room is used as a combination of living and dining or solely as a relaxation area. In both cases the parents' bedroom has an ensuite bathroom.

2.4.2 Building Materials

A list of the building elements is acquired through interviewing the owners, researching common used materials for the time and region, or through existing construction plans from the architect. The element properties are added after online research in the database IBO Passivhaus-Bauteilkatalog from baubook.info, local wholesale dealers or directly at the manufacturer's homepage and the calculation atlas SIRADOS.

The following building materials attributes shown in Table 1 are needed for the simulations and calculations:

- Thickness d [m]
- Conductivity λ [$W.m^{-1}.K^{-1}$]
- Specific heat capacity c [$J.kg^{-1}.K^{-1}$]
- Density ρ [$kg.m^{-3}$]
- Global warming potential GWP [$CO_2.kg^{-1}$]
- Acidification potential AP [$SO_2.kg^{-1}$]
- Non-renewable energy source requirement $PEC_{n.r.}$ [$MJ.kg^{-1}$]
- Costs per unit [EUR]

Table 1, attributes of building materials

	d [m]	λ [$W.m^{-1}.K^{-1}$]	c [$J.kg^{-1}.K^{-1}$]	ρ [$kg.m^{-3}$]	GWP [$CO_2.kg^{-1}$]	AP [$SO_2.kg^{-1}$]	$PEC_{n.r.}$ [$MJ.kg^{-1}$]	Cost per m^2 [EUR]
brick	0.3500	0.2590	1,000	1,230	0.1100	0.0004	2.3800	-
cement screed	0.0600	1.7000	1,116	2,000	0.1300	0.0003	1.0800	14.60
glued parquet	0.0200	0.1500	1,600	740	0.2800	0.0063	18.7000	80.00
gypsum plaster board	0.0150	0.2100	1,000	850	0.2000	0.0007	4.3400	14.87
insulation panel	0.2000	0.0330	1,500	18	3.4500	0.0223	102.0000	49.40
isocell vapor barrier	0.0001*	0.2200	792	600	2.8200	0.0240	93.7000	3.60
isover insulation	0.1400	0.0340	1,030	21	2.2600	0.0160	49.8000	25.39
lime-gypsum plasters	0.0150	0.7000	920	1,300	0.2300	0.0008	2.2200	14.01
mineral adhesive	0.0040	1.0000	1,116	1,800	0.3400	0.0011	4.4300	-

*0.0001 m is the suggested value for simulations and calculations (Baubook, 2014)

	d [m]	λ [W.m^{-1}.K^{-1}]	c [J.kg^{-1}.K^{-1}]	ρ [kg.m^{-3}]	GWP [CO_2.kg^{-1}]	AP [SO_2.kg^{-1}]]	$PEC_{n.r.}$ [MJ.kg^{-1}]	Cost per m² [EUR]
parquet	0.0200	0.1500	1,600	740	0.0652	0.0051	17.8000	80.00
polyethylene film	0.0001*	0.5000	1,260	980	2.5500	0.0253	93.4000	1.33
polystyrol	0.1000	0.0400	1,000	18	3.4500	0.0223	102.0000	16.69
	0.1200	0.0380	1,450	20				22.20
porotherm brick	0.2500	0.2590	1,000	864	0.1700	0.0006	2.4900	81.67
	0.1200	0.3300						45.51
reinforced concrete	0.2000	2.5000	880	2,400	0.1500	0.0005	1.1700	29.01
roof tile	0.0127	1.5900	1,260	1,920	0.1780	0.0003	1.4900	34.24
silicone resin plasters	0.0020	0.7000	1,000	1,700	0.4600	0.0025	12.4000	15.94
timber	0.2000	0.1200	2,100	500	-1.6900	0.0015	2.2700	7.49

*0.0001 m is the suggested value for simulations and calculations (Baubook, 2014)

2.5 Thermal Simulation

With the finished 2D plans and complete attribute lists, the simulations can progress. The first step was to build up 3D models in ArchiCAD according the 2D plans. The finished 3D models then have two purposes. Using an interface plug-in, it is possible to export the model as an *.aph file and import it to ArchiPhysik for further use. By assigning the correct building components in both programmes, first comparisons can be done via the output of energy certificates.

Saving the models as a *.3ds file allows importing to SketchUp. With the plug-in OpenStudio, the existing file needs to be remodelled as building surfaces and thermal zones as a preparation for the upcoming simulation. Once the remodelling is done, an *.idf file is generated, which can be opened in the final simulation software EnergyPlus for further adjustments for simulating. After this is successfully done, the heating demands, temperature, relative humidity and solar gains of each thermal zone are acquired.

2.5.1 3D Models

For the thermal simulations it is necessary to set thermal zones and boundary conditions. It was decided to model every room as a thermal zone of its own (Figure 8). This allows more flexibility and different thermal zones can be combined as a group and activated or deactivated when required.

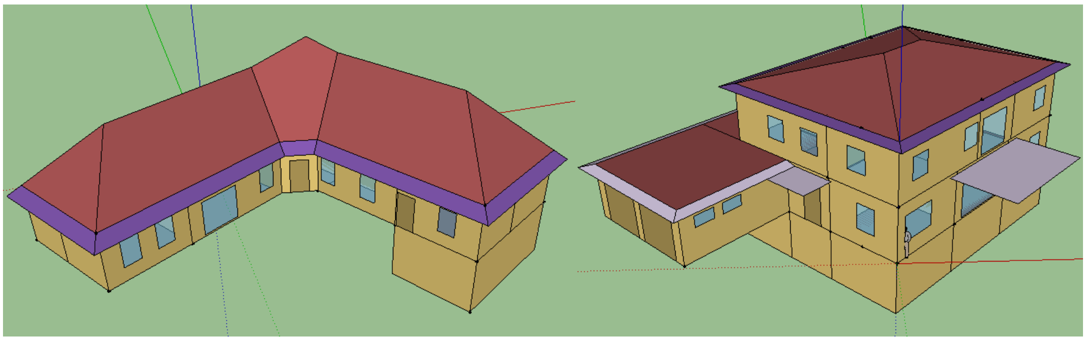


Figure 8, image of 3D model of House 1950+ and House 2014

After setting the boundary conditions *adiabatic, unconditioned, outside* and *ground* to the designated elements, shading elements are modelled for simulating realistic measures against summer overheating (Figure 9). This is the last modification in the 3D model and the geometry is ready to be imported to EnergyPlus.

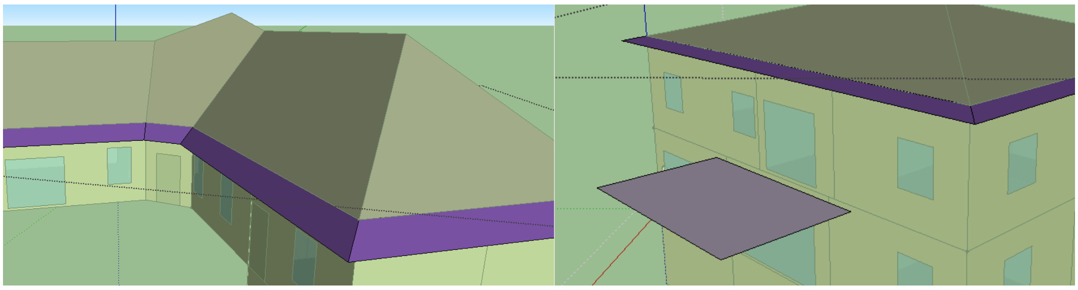
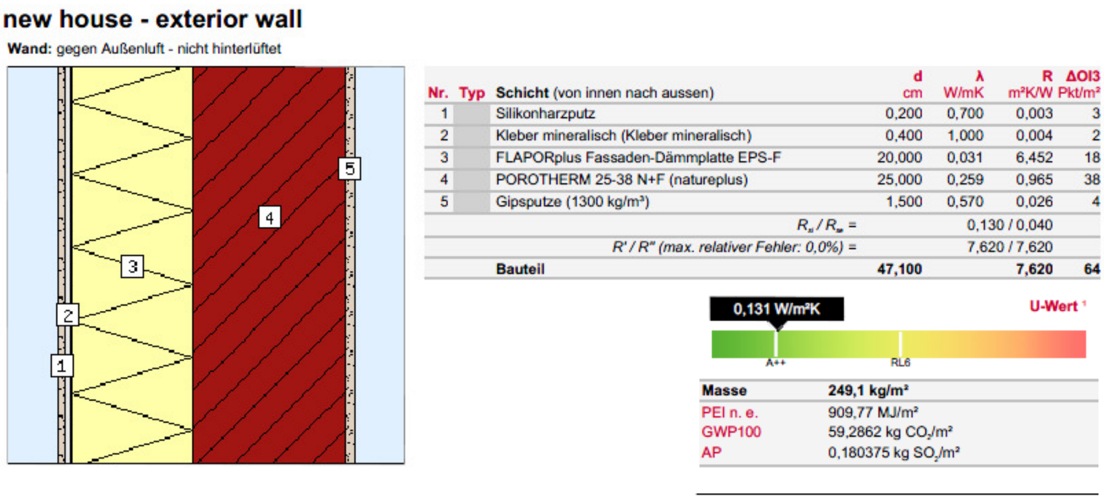


Figure 9, image of shading elements of House 1950+ and House 2014

2.5.2 Building Elements

All the necessary building elements are generated in the IBO Passivhaus-Bauteilkatalog in order to get the information seen in Figure 10. The full detailed list of building elements are found in the Appendix.



Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch (Kleber mineralisch)	0,400	1,000	0,004	2
3		FLAPORplus Fassaden-Dämmplatte EPS-F	20,000	0,031	6,452	18
4		POROTHERM 25-38 N+F (natureplus)	25,000	0,259	0,965	38
5		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R'' (max. relativer Fehler: 0,0%) =			7,620 / 7,620	
		Bauteil	**47,100**		**7,620**	**64**

Masse	**249,1 kg/m²**
PEI n. e.	909,77 MJ/m²
GWP100	59,2862 kg CO_2/m²
AP	0,180375 kg SO_2/m²

Figure 10, attributes of building element: exterior wall

Thickness, conductivity, density and specific heat are input values in EnergyPlus. For ArchiPhysik this information is taken from an internal database and the U-values are calculated automatically. The U-values of the building elements that were used in this project are seen in Table 2. The building elements of scenario #2.1, #2.2, #3.1 and #3.2 have both the same retrofitted components. For any unknown values, the default U-values suggested in the OIB standards 6 (2011) are chosen.

Table 2, U-values of building elements in $W.m^{-2}.K^{-1}$

	House 1950	House 1950+	House 2014
windows	2.50	1.10	0.90–1.10
doors	2.50	1.10	1.10
exterior wall	1.69	0.13	0.14
interior walls	0.80-3.60	0.80-3.60	0.80–1.70
slab to ground	2.19	0.14	0.16
slab to basement	2.19	0.14	0.16
slab to attic	0.77	0.13	0.11
roof	1.16	0.12	0.13

2.5.3 EnergyPlus Input

Apart from the already mentioned input values, the following variables have to be entered as well into EnergyPlus in order to get successful results:

- People
- Electrical equipment
- Ventilation
- Thermostat
- Ground heat transfer
- Weather data

Internal heat gains from people and electrical equipment are important factors in thermal simulations. Therefore, the activity level of the occupancy and usage of electric devices are added via utilizing the scheduled activities for the functional rooms, the living room, bed rooms, bath rooms and kitchen.

The schedule of the living room as seen in Table 3 shows the assumptions that are made for this room. For better comparison, the schedules are mostly the same for all the different scenarios. A complete list of schedules is found in the Appendix.

Table 3, activity schedule of living room

	Time	Occupants	Equipment [W]
weekdays	00:00-07:00	0	10
	07:00-12:00	2	60
	12:00-17:00	4	200
	17:00-21:00	1	60
	21:00-22:00	2	60
	22:00-24:00	0	10
weekends	00:00-07:00	0	10
	07:00-12:00	4	150
	12:00-17:00	5	200
	17:00-21:00	4	150
	21:00-22:00	0	10

Since in none of the scenarios mechanical ventilation is used, the buildings rely on natural ventilation by opening windows and doors for obtaining fresh air. The input schedules for the ventilation is divided into winter and summer schedules as seen in Table 4.

In winter a constant air change rate (ACR) of 0.6 $h^{-1}$is assumed. In order to prevent overheating and to improve the indoor air quality in summer, during peak activities windows are fully opened, which is resembled by an ACR of 8.0 h^{-1}. Tilted windows are resembled by an ACR of 2.0 h^{-1} in these simulations.

Table 4, schedule of seasonal ventilation

Season	Date	Time	ACR [h^{-1}]
Winter	01.10.-30.04.	00:00-24:00	0.6
Summer	01.05.-30.09.	00:00-08:00	2.0
		08:00-22:00	8.0
		22:00-24:00	2.0

During the winter period between October and May the heating is set to 20° C according to OIB guidelines (OIB Richtlinie 6, 2011). No heating is activated in the summer months and none of the simulated buildings have any mechanical cooling.

Since all the buildings have basements, the auxiliary tool Ground Heat Transfer was used for achieving a more realistic simulation. The complete input parameters for this tool can be found in the Appendix.

No matter how precise the previously mentioned input values are, in order to get genuine simulation results, proper weather data for the specific location of Unterwart is required. Since no measured data is available for this town, a weather file has to be created. By using the meteorological catalogue of Meteonorm and the precise coordinates of Unterwart 47°16’N 16°14’E; the data for this location was generated by interpolating data of six surrounding locations. A detailed report of the weather data of Unterwart can be found in the Appendix.

With all the information, the heat demand, indoor temperature and solar gains are simulated in EnergyPlus. Overheating will be determined by how many times the temperature in the rooms rise above 27° C. These hours will be accumulated and presented as Kelvin-hours as a means of comparison.

2.6 Environmental Factors

For scenarios #2.1, #2.2, #3.1, #3.2 and #4, which are the renovated House 1950, the extended and renovated House 1950 and House 2014, the environmental impact of the renovation and construction in form of a life cycle assessment (LCA) are calculated. The emission of heating over 30 years is compared to each other including scenario #1. As a base of calculation for the LCA OI3 indicators from the IBO guidelines 2013 are used. The guidelines suggest seven groups of flexible envelope boundaries for the calculations. The boundary groups (BG) indicate the level of detail of building elements that are used in the scheme and are always base on the previews group as seen in Table 1 .

Table 5, flexible envelope boundaries taken from Guidelines to calculating the OI3 indicators V3.0

BG0	structures of the thermal building envelope excl. damp proofing (in the floor slab and in the roof outside the insulation layer) excl. rear-ventilated façade elements excl. roof cladding
BG1	Basing on BG0 all structures of the thermal building envelope incl. Intermediate floors
BG2	Basing on BG1, incl. inside walls (dividing elements)
BG3	Basing on BG2, incl. inside walls (all inside walls) incl. complete basement incl. non-heated buffer spaces (complete building) excl. direct access
BG4	Basing on BG3, incl. direct access (stairways, covered walkways etc.)
BG5	Basing on BG4, incl. housing technology
BG6	Basing on BG5, incl. all accesses incl. adjoining buildings

For the calculation of the indicators boundary group level 3 with alterations was chosen. The roofs as major parts of the building envelope were included in all scenarios, and the basement of House 2014 was not included for better comparison to House 1950+.

The list of attributes of building materials introduced in chapter 2.4.2 already included the necessary information needed for the following calculation: non-renewable energy source requirement ($PEC_{n.r.}$), global warming potential (GWP) and acidification potential (AP). Since the values are listed for every single material individually, the $PEC_{n.r}$, GWP and AP the accumulated values for the building components are calculated as seen chapter 2.5.2.

The last missing factor for the calculation base is the surface area of the envelope and inside elements, which is represented in Table 6.

Table 6, list of surface area of building elements in m²

	Scenario #2.1, #2.2 Renov. House 1950	Scenario #3.1, #3.2 House 1950+	Scenario #4 House 2014
Exterior wall	130	180	194
Interior wall	-	40	112 (12cm) 70 (25cm)
Exterior slab	140	220	150
Interior slab (adiabatic)	-	-	150
Interior slab (attic)	140	220	150
Roof	190	310	180

2.6.1 Calculating the sub-indicators OI_{PECnr}, OI_{GWP}, OI_{AP}

To calculate the environmental indicator of a building element, following Formula 1 is used:

$$OI3_{KON} = 1/3\ OI_{PECnr} + 1/3\ OI_{GWP} + 1/3\ OI_{AP}$$

Formula 1, $OI3_{KON}$

$OI3_{KON}$ … environmental indicator for 1m² of a structure
OI_{PECnr} … environmental indicator of non-renewable primary energy content
OI_{GWP} … environmental indicator of global warming potential
OI_{AP} … environmental indicator of acidification potential

The following paragraphs of formulas and figures are outtakes from the guidelines to calculating the OI3 indicators Version 3, 2013 and discuss the method of calculation.

"To calculate the OIPECnr the following line chart Figure 11 was drawn on the basis of actual structural and building data: To convert the MJ per 1 m² of structure into OIPECnr points, the linear function f(x) = 1/10(x-500) is used.*

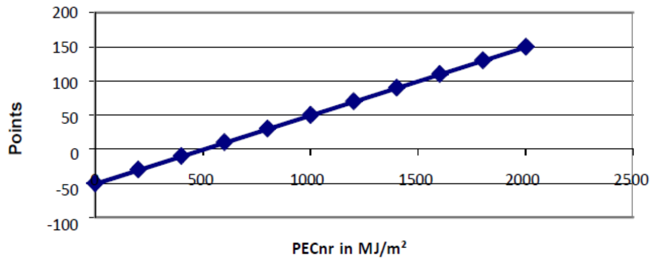


Figure 11, Conversion of PEC_{nr} in $MJ.m^{-2}$ into OI_{PECnr} points

To calculate the OIGWP, the following line chart Figure 12 was drawn on the basis of actual structural and building data: To convert the kg CO2 eq. per 1 m² of structure into OIGWP points, the linear function f(x) = 1/2(x+50) is used.*

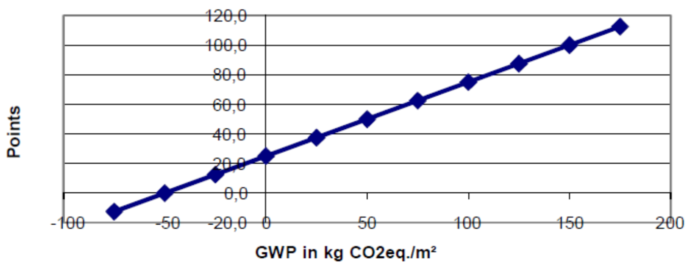


Figure 12, Conversion of GWP in kg CO_2 eq. into OI_{GWP} points

To calculate the OIAP, the following line chart Figure 13 was drawn on the basis of actual structural and building data: To convert the kg SO2 eq. per 1 m² of structure into OIGWP points, the linear function f(x) = 100/0.25(x-0.21) is used."*

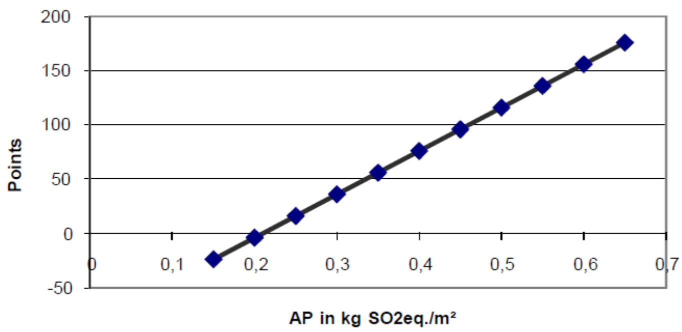


Figure 13, Conversion of AP in kg SO_2 eq. into OI_{AP} points

Besides the OI3 indicators of the building elements, the heat consumption of the buildings is also causing factors that impact the environment. House 1950 is the only building out of the six scenarios, which is heating with natural gas. In these scenarios it is assumed that the other buildings are heating with biomass from the district.

Using the monthly and annual heating demands that resulted from the previous thermal simulation and the carbon dioxide values of the CO_2 calculator from the energy globe portal as seen in Table 7, the emission of the next 30 years of the four scenarios is estimated. The degree of efficiency for the gas boiler is set to 77 % and the district heating to 88 % (energiesparhaus.at, 2014).

Table 7, CO_2 values of heating sources

Source of heating	kg CO_2 per kWh
natural gas	0.29
district heating biomass	0.03

2.7 Cost Estimation

The final comparison will look at the costs of renovating, extending and building. The basis for the estimation is the scheme for cost calculation of construction costs ("*Bauwerkskosten*") from ÖNORM 1801-1.

In Table 8 the positions, that are relevant for the cost estimation in this thesis, are listed. The complete table of all the construction cost can be found in the appendix.

Table 8, relevant positions of construction costs from ÖNORM 1801-1

BWK	construction costs		
2	BWR	building shell	
	2D	horizontal building construction	
		2D.01	slab construction
		2D.02	stair construction
		2D.03	roof construction
	2E	vertical building construction	
		2E.01	exterior wall construction
		2E.02	interior wall construction
3	BWT	building engineering	
4	BWA	building finishing	
	4B	roof finishing	
		4B.01	roof membrane
	4C	facade finishing	
		4C.01	facade paneling
		4C.02	facade openings
	4D	interior finishing	
		4D.01	floor covering
		4D.02	exterior wall finishing
		4D.03	ceiling finishing
		4D.04	doors and windows
		4D.05	interior wall finishing

Furthermore the heat demand over 30 years will be translated to costs using the current market prices (02/08/14): EUR 0.0735 per kWh for natural gas and EUR 0.0936 per kWh for district heating (IWO Austria, 2014). For the calculation an annual price increase of 4 % and a discount rate of 5.5 % are chosen (DGNB/ÖGNI, 2013). As mentioned before the degree of efficiency for the gas boiler is set to 77 % and the district heating to 88 % (energiesparhaus.at, 2014). To receive today's investment value the predicted costs are converted with the present value in Formula 2.

$$PV = C / (1+i)^n$$

Formula 2, present value

PV … present value
C … future costs
i … interest rate / discount rate
n … number of compound years

Chapter 3

Results

3.1 Overview

This chapter will feature the results of simulations and calculations that have been described in the previous chapter. The outcomes will be displayed separately for every scenario and they will then be discussed and interpreted in Chapter 4.

The thermal performances of the scenarios are presented with energy certificates generated from ArchiPhysik and annual heating demand, overheating and solar gain outcomes are taken from the simulations in EnergyPlus.

For all the internal and external building elements the OI3 indicators are shown in the scheme of calculating the OI3 points. As for scenarios #2.1, #2.2, #3.1, #3.2 and #4 a thorough list of the construction costs are displayed in this chapter.

3.1.1 Scenario #1

The area of the thermal envelope for scenario #1 sums up to 463 m² and 3.2 % of the envelope is transparent. The net living area is 118.7 m² (gross: 146.0 m²) and the net volume is 367.97 m³ (gross: 540.20 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 238 kWh.m^{-2} as seen in Figure 14. The monthly heating demand simulated from EnergyPlus is displayed in Figure 15. In one year this scenario shows an annual heating demand of 19,345 kWh, 118 Kh of overheating and 3,319 kWh solar gains through windows. The peak demand is simulated for the month of January with 4,363 kWh and solar gains of 259 kWh. The highest solar gains are in July with 439 kWh and 45 Kh of overheating.

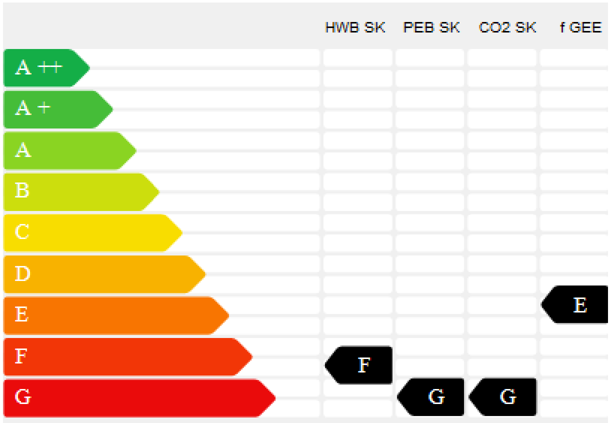


Figure 14, energy certificate of scenario #1

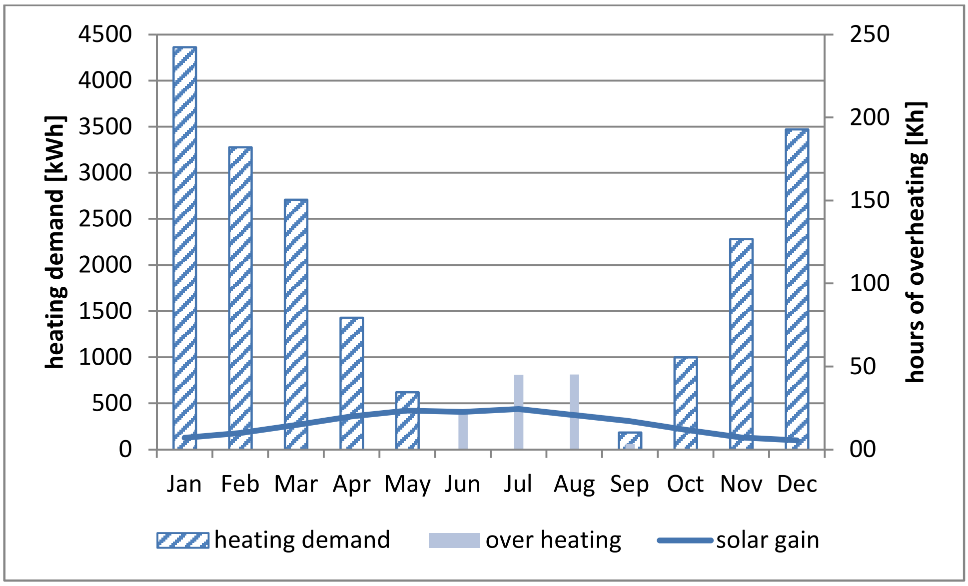


Figure 15, monthly heating demand and solar gains in kWh, overheating in Kh of scenario #1

Table 9, environmental impact values, absolute and per m² and eco-costs of scenario #1

absolute values

$PEC_{n.r}$	-	MJ			
GWP	-	kg CO_2	€ 135/ 1,000 kg CO	€	-
AP	-	kg SO_2	€ 8.25/ kg SO2	€	-
30 years of heating	185,133	kg CO_2	€ 135/ 1,000 kg CO	€	24,992.94
			total eco-costs	**€**	**24,992.94**

values per m² living area

$PEC_{n.r}$	-	$MJ.m^{-2}$			
GWP	-	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	-
AP	-	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	-
30 years of heating	1,543	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	208.27
			total eco-costs per m²	**€**	**208.27**

The annual heating demand of 19,345 kWh covered by natural gases over the period of 30 years translates to 185,133 kg CO2 and a present value of EUR 46,558.57 costs for heating with natural gas.

The total cost estimation for this scenario including the eco-costs and the present value of heating is at EUR 71,551.51

Summary of scenario #1

net floor area	119	m²
envelope area	463	m²
glazing area	15	m²
annual heating demand	19,345	kWh
overheating	118	Kh
OI3 grading	-	points
estimated costs	71,551.51	EUR

3.1.2 Scenario #2.1

The area of the thermal envelope for scenario #2.1 sums up to 463 m² and 3.2 % of the envelope is transparent. The net living area is 118.7 m² (gross: 146.0 m²) and the net volume is 367.97 m³ (gross: 562.10 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 49 kWh.m^{-2} as seen in Figure 16. The monthly heating demand simulated from EnergyPlus is displayed in Figure 17. In one year this scenario shows an annual heating demand of 10,732 kWh, 79 Kh of overheating and 3,319 kWh solar gains through windows. The peak demand is simulated for the month of January with 2,376 kWh and solar gains of 250 kWh. The highest solar gains are in July with 439 kWh and 35 Kh of overheating.

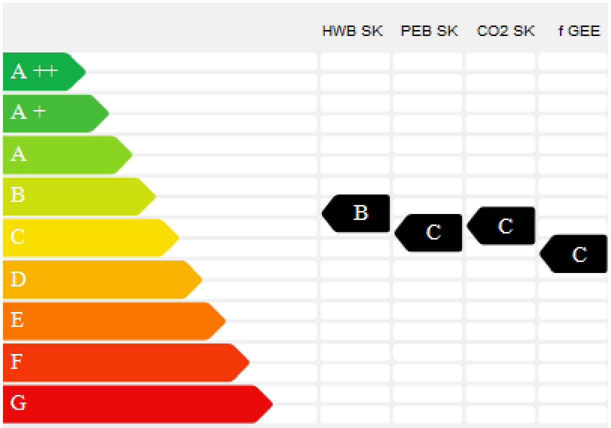


Figure 16, energy certificate of scenario #2.1

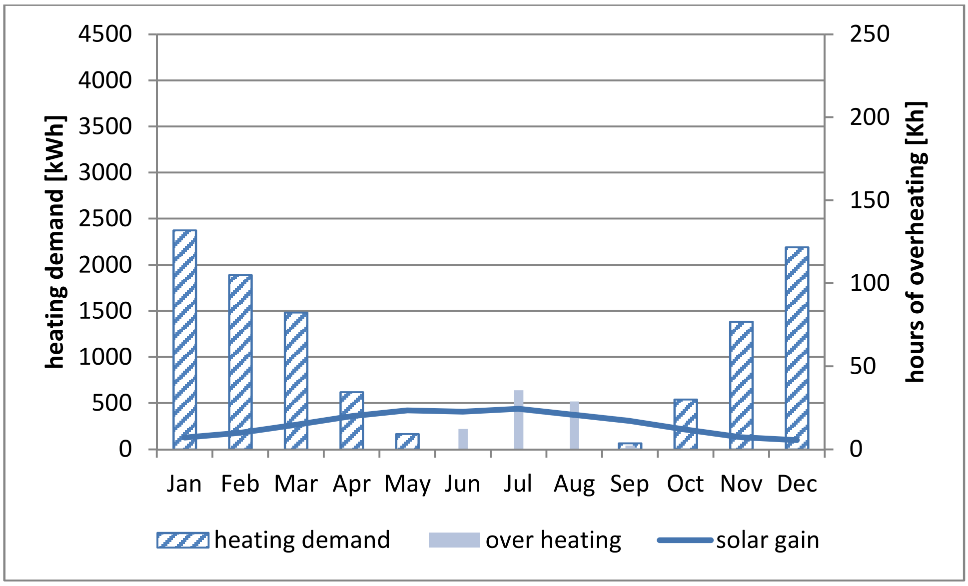


Figure 17, monthly heating demand and solar gains in kWh, overheating in Kh of scenario #2.1

In the following Table 10 the OI3 indicator of the building elements are listed. The values of the building elements are the impact of only the materials used for retrofitting.

Table 10, environmental indicator of scenario #2.1

exterior wall				130 m²	
$PEC_{n.r}$ [MJ per m²]	148.3400	0	points		
GWP [kg CO2 eq. per m²]	6.2538	28	points		
AP [kg SO2 eq. per m²]	0.0224	0	points		
		9	points per m²		1,170 points

exterior slab				140 m²	
$PEC_{n.r}$ [MJ per m²]	971.4600	47	points		
GWP [kg CO2 eq. per m²]	84.3900	67	points		
AP [kg SO2 eq. per m²]	0.2398	12	points		
		42	points per m²		5,880 points

slab to attic				140 m²	
$PEC_{n.r}$ [MJ per m²]	296.6800	0	points		
GWP [kg CO2 eq. per m²]	12.5076	31	points		
AP [kg SO2 eq. per m²]	0.0447	0	points		
		10	points per m²		1,400 points

total OI3 points	8,450 points
OI3 points per m²	**21 points**

Table 11, construction costs according ÖNORM 1801-1 of scenario #2.1

2	BWR	building shell							€	-
3	BWT	building engineering							€	-
4	BWA	building finishing								
	4C	facade finishing								
		4C.01	facade paneling							
			silicone resin plasters	€	15.94					
			insulation panel	€	49.40					
				€	65.34	x	130 m²	=	€	8,494.20
		4C.02	facade openings							
			remove window	€	33.80					
			window	€	960.00					
			window installation	€	11.89					
				€	1,005.69	x	11 pcs	=	€	11,062.59
			remove door	€	95.80					
			entrance door	€	1,645.00					
				€	1,740.80	x	2 pcs	=	€	3,481.60
	4D	interior finishing								
		4D.01	floor covering							
			polystyrol	€	16.69					
			polyethylene film	€	1.33					
			cement screed	€	14.60					
			parquet	€	80.00					
				€	112.62	x	140 m²	=	€	15,766.80
		4D.03	ceiling finishing							
			polystyrol	€	16.69	x	140 m²	=	€	2,336.60
				total construction costs					**€**	**41,141.79**

Table 12, environmental impact values, absolute and per m² and eco-costs of scenario #2.1

absolute values

$PEC_{n.r}$	196,824	MJ			
GWP	14,378	kg CO_2	€ 135/ 1,000 kg CO	€	1,941.03
AP	43	kg SO_2	€ 8.25/ kg SO2	€	354.75
30 years of heating	12,556	kg CO_2	€ 135/ 1,000 kg CO	€	1,695.09
			total eco-costs	**€**	**3,990.87**

values per m² living area

$PEC_{n.r}$	1,640	$MJ.m^{-2}$			
GWP	120	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	16.18
AP	0.36	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	2.96
30 years of heating	105	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	14.13
			total eco-costs per m²	**€**	**33.26**

The construction costs for the retrofit are listed in Table 11 and are estimated to EUR 41,141.79 The annual heating demand of 10,732 kWh covered by district heating biomass over the period of 30 years translates to 12,556 kg CO2 and a present value of EUR 28,780.45 costs for heating.

The total cost estimation for this scenario including the eco-costs, the present value and the construction costs of heating is at EUR 73,913.11

Summary of scenario #2.1

net floor area	119	m²
envelope area	463	m²
glazing area	15	m²
annual heating demand	10,732	kWh
overheating	79	Kh
OI3 grading	21	points
estimated costs	73,913.11	EUR

3.1.3 Scenario #2.2

The area of the thermal envelope for scenario #2.2 sums up to 511 m² and 2.9 % of the envelope is transparent. The net living area is 118.7 m² (gross: 146.0 m²) and the net volume is 451.1 m³ (gross: 689.1 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 88 kWh.m^{-2} as seen in Figure 18. The monthly heating demand simulated from EnergyPlus is displayed in Figure 19. In one year this scenario shows an annual heating demand of 11,044 kWh, 72 Kh of overheating and 3,319 kWh solar gains through windows. The peak demand is simulated for the month of January with 2,458 kWh and solar gains of 253 kWh. The highest solar gains are in July with 439 kWh and 33 Kh of overheating.

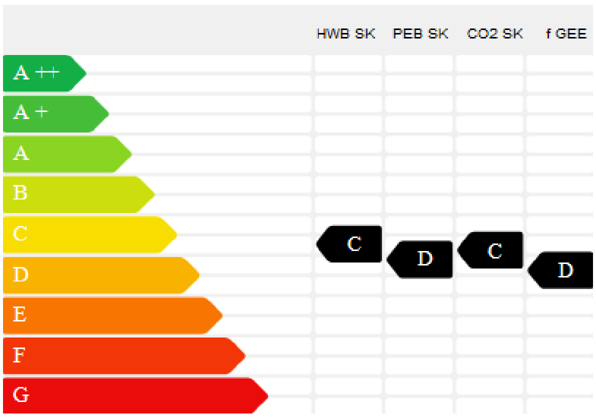


Figure 18, energy certificate of scenario #2.2

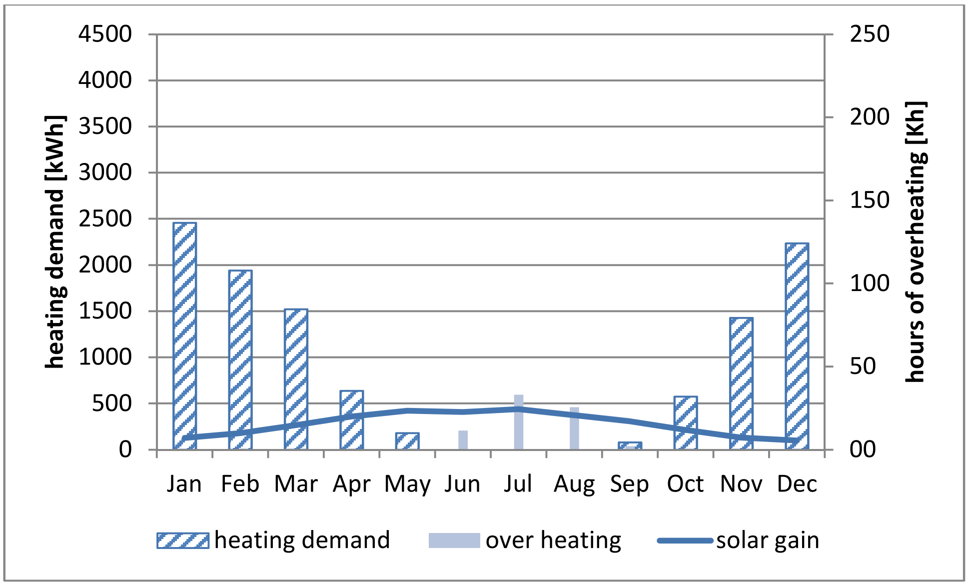


Figure 19, monthly heating demand and solar gains in kWh, overheating in Kh of scenario #2.2

In the following Table 10 the OI3 indicator of the building elements are listed. The values of the building elements are the impact of only the materials used for retrofitting.

Table 13, environmental indicator of scenario #2.2

exterior wall				130 m²	
$PEC_{n.r}$ [MJ per m²]	148.3400	0	points		
GWP [kg CO2 eq. per m²]	6.2538	28	points		
AP [kg SO2 eq. per m²]	0.0224	0	points		
		9	points per m²		1,170 points

exterior slab				140 m²	
$PEC_{n.r}$ [MJ per m²]	971.4600	47	points		
GWP [kg CO2 eq. per m²]	84.3900	67	points		
AP [kg SO2 eq. per m²]	0.2398	12	points		
		42	points per m²		5,880 points

roof				190 m²	
$PEC_{n.r}$ [MJ per m²]	556.9600	6	points		
GWP [kg CO2 eq. per m²]	-21.9125	14	points		
AP [kg SO2 eq. per m²]	0.1588	0	points		
		7	points per m²		1,250 points

total OI3 points	8,300 points
OI3 points per m²	**18 points**

Table 14, construction costs according ÖNORM 1801-1 of scenario #2.2

2	BWR	building shell						€	-
3	BWT	building engineering						€	-
4	BWA	building finishing							
	4B	roof finishing							
		4B.01	roof membrane						
			roof tile	€	34.24				
			isover insulation	€	25.39				
				€	59.63	190 m²		€	11,329.70
	4C	facade finishing							
		4C.01	facade paneling						
			silicone resin plasters	€	15.94				
			insulation panel	€	49.40				
				€	65.34	x 130 m²	=	€	8,494.20
		4C.02	facade openings						
			remove window	€	33.80				
			window	€	960.00				
			window installation	€	11.89				
				€	1,005.69	x 11 pcs	=	€	11,062.59
			remove door	€	95.80				
			entrance door	€	1,645.00				
				€	1,740.80	x 2 pcs	=	€	3,481.60
	4D	interior finishing							
		4D.01	floor covering						
			polystyrol	€	16.69				
			polyethylene film	€	1.33				
			cement screed	€	14.60				
			parquet	€	80.00				
				€	112.62	x 140 m²	=	€	15,766.80
				total construction costs				**€**	**50,134.89**

Table 15, environmental impact values, absolute and per m² and eco-costs of scenario #2.2

absolute values

$PEC_{n.r}$	261,111	MJ			
GWP	8,464	kg CO_2	€ 135/ 1,000 kg CO	€	1,142.64
AP	67	kg SO_2	€ 8.25/ kg SO2	€	552.75
30 years of heating	12,922	kg CO_2	€ 135/ 1,000 kg CO	€	1,744.47
			total eco-costs	**€**	**3,439.86**

values per m² living area

$PEC_{n.r}$	2,176	$MJ.m^{-2}$			
GWP	71	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	9.52
AP	0.56	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	4.61
30 years of heating	108	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	14.54
			total eco-costs per m²	**€**	**28.67**

The construction costs for the retrofit are listed in Table 14 and are estimated to EUR 50,134.89 The annual heating demand of 11,044 kWh covered by district heating biomass over the period of 30 years translates to 12,922 kg CO2 and a present value of EUR 29,618.91 costs for heating.

The total cost estimation for this scenario including the eco-costs, the present value and the construction costs of heating is at EUR 83,193.66

Summary of scenario #2.2

net floor area	119	m²
envelope area	511	m²
glazing area	15	m²
annual heating demand	11,044	kWh
overheating	72	Kh
OI3 grading	18	points
estimated costs	83,193.66	EUR

3.1.4 Scenario #3.1

The area of the thermal envelope for scenario #3.1 sums up to 688.71 m² and 4.2 % of the envelope is transparent. The net living area is 189.4 m² (gross: 227.3 m²) and the net volume is 587.1 m³ (gross: 875.11 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 41 kWh.m^{-2} as seen in Figure 20. The monthly heating demand simulated from EnergyPlus is displayed in Figure 21. In one year this scenario shows an annual heating demand of 16,212 kWh, 80 Kh of overheating and 6,929 kWh solar gains through windows. The peak demand is simulated for the month of January with 3,616 kWh and solar gains of 197 kWh. The highest solar gains are in July with 830 kWh and 38 Kh of overheating.

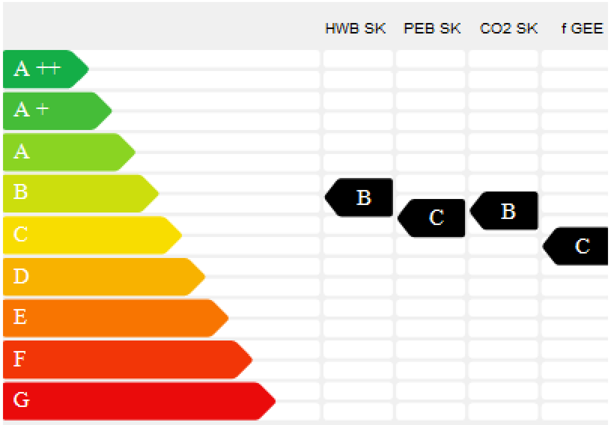


Figure 20, energy certificate of scenario #3.1

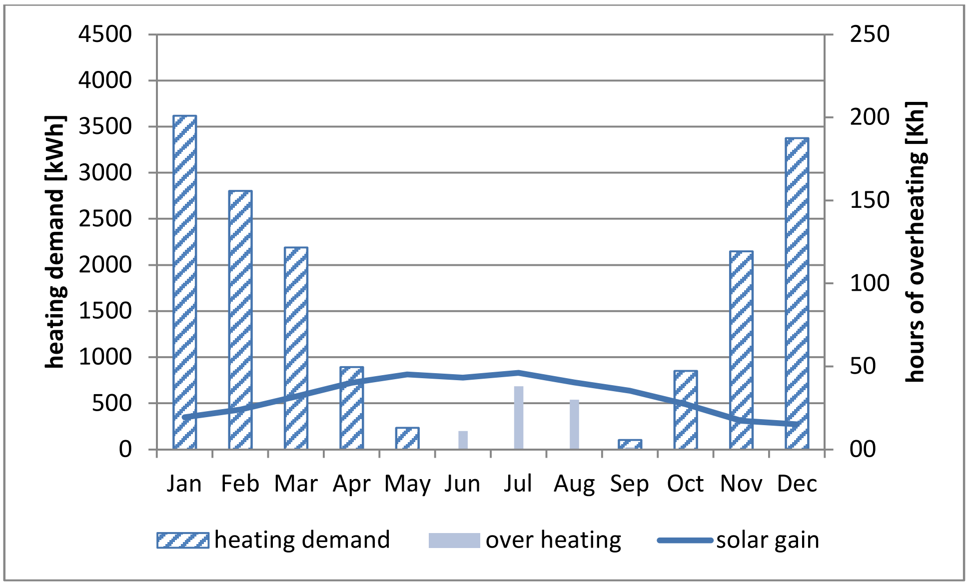


Figure 21, monthly heating demand and solar gains in kWh, overheating in Kh of scenario #3.1

In the following Table 10 the OI3 indicator of the building elements are listed. The values of the building elements are the impact of only the materials used for retrofitting.

Table 16, environmental indicator of scenario #3.1

exterior wall			180 m²	
$PEC_{n.r}$ [MJ per m²]	148.3400	0	points	
GWP [kg CO2 eq. per m²]	6.2538	28	points	
AP [kg SO2 eq. per m²]	0.0224	0	points	
		9	points per m²	1,620 points

interior wall			40 m²	
$PEC_{n.r}$ [MJ per m²]	318.2800	0	points	
GWP [kg CO2 eq. per m²]	24.0153	37	points	
AP [kg SO2 eq. per m²]	0.0695	0	points	
		12	points per m²	480 points

exterior slab			220 m²	
$PEC_{n.r}$ [MJ per m²]	971.4600	47	points	
GWP [kg CO2 eq. per m²]	84.3900	67	points	
AP [kg SO2 eq. per m²]	0.2398	12	points	
		42	points per m²	9,240 points

slab to attic			220 m²	
$PEC_{n.r}$ [MJ per m²]	296.6800	0	points	
GWP [kg CO2 eq. per m²]	12.5076	31	points	
AP [kg SO2 eq. per m²]	0.0447	0	points	
		10	points per m²	2,200 points

total OI3 points	13,540 points
OI3 points per m²	**21 points**

Table 17, construction costs according ÖNORM 1801-1 of scenario #3.1

2	BWR	building shell						
	2E	vertical building construction						
		2E.02	interior wall construction					
			porotherm brick	€	45.51	x 40 m²	= €	1,820.40
3	BWT	building engineering					€	-
4	BWA	building finishing						
	4C	facade finishing						
		4C.01	facade paneling					
			silicone resin plasters	€	15.94			
			insulation panel	€	49.40			
				€	65.34	x 180 m²	= €	11,761.20
		4C.02	facade openings					
			remove window	€	33.80			
			window installation	€	11.89			
				€	45.69	x 11 pcs	= €	502.59
			window	€	960.00	x 19 pcs	= €	18,240.00
			remove door	€	95.80			
			entrance door	€	1,645.00			
			door installation	€	11.89			
				€	1,752.69	x 2 pcs	= €	3,505.38
	4D	interior finishing						
		4D.01	floor covering					
			polystyrol	€	16.69			
			polyethylene film	€	1.33			
			cement screed	€	14.60			
			parquet	€	80.00			
				€	112.62	x 220 m²	= €	24,776.40
						balance	**€**	**60,605.97**

				balance	**= €**	**60,605.97**
4D.02	exterior wall finishing					
	lime-gypsum plasters	€	14.01	x 50 m²	= €	700.50
4D.03	ceiling finishing					
	lime-gypsum plasters	€	14.01	x 80 m²	= €	1,120.80
4D.04	doors and windows					
	door	€	270.00			
	door installation	€	4.30			
		€	274.30	x 4 pcs	= €	1,097.20
4D.05	interior wall finishing					
	lime-gypsum plasters	€	14.01	x 80 m²	= €	1,120.80
				total construction costs	**€**	**64,645.27**

Table 18, environmental impact values, absolute and per m² and eco-costs of scenario #3.1

absolute values

$PEC_{n.r}$	318,423	MJ			
GWP	23,403	kg CO_2	€ 135/ 1,000 kg CO	€	3,159.41
AP	69	kg SO_2	€ 8.25/ kg SO2	€	569.25
30 years of heating	18,969	kg CO_2	€ 135/ 1,000 kg CO	€	2,560.75
			total eco-costs	**€**	**6,289.40**

values per m² living area

$PEC_{n.r}$	1,676	$MJ.m^{-2}$			
GWP	123	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	16.63
AP	0.37	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	3.00
30 years of heating	100	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	13.48
			total eco-costs per m²	**€**	**33.10**

The construction costs for the retrofit and the extension are listed in Table 17 and are estimated to EUR 64,645.27 The annual heating demand of 16,212 kWh covered by district heating biomass over the period of 30 years translates to 18,969 kg CO2 and a present value of EUR 43,478.23 costs for heating.

The total cost estimation for this scenario including the eco-costs, the present value and the construction costs of heating is at EUR 108,941.04

Summary of scenario #3.1

net floor area	189	m²
envelope area	689	m²
glazing area	29	m²
annual heating demand	16,212	kWh
overheating	80	Kh
OI3 grading	21	points
estimated costs	108,941.04	EUR

3.1.5 Scenario #3.2

The area of the thermal envelope for scenario #3.2 sums up to 779.1 m² and 3.7 % of the envelope is transparent. The net living area is 189.4 m² (gross: 227.3 m²) and the net volume is 684.89 m³ (gross: 1,020.80 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 76 kWh.m^{-2} as seen in Figure 20. The monthly heating demand simulated from EnergyPlus is displayed in Figure 21. In one year this scenario shows an annual heating demand of 16,628 kWh, 72 Kh of overheating and 6,929 kWh solar gains through windows. The peak demand is simulated for the month of January with 3,721 kWh and solar gains of 197 kWh. The highest solar gains are in July with 830 kWh and 35 Kh of overheating.

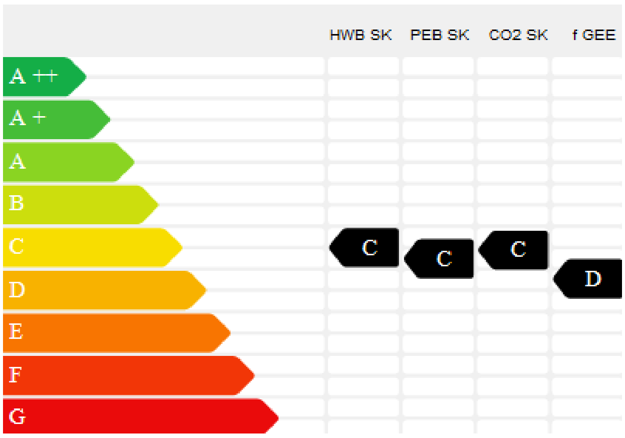


Figure 22, energy certificate of scenario #3.2

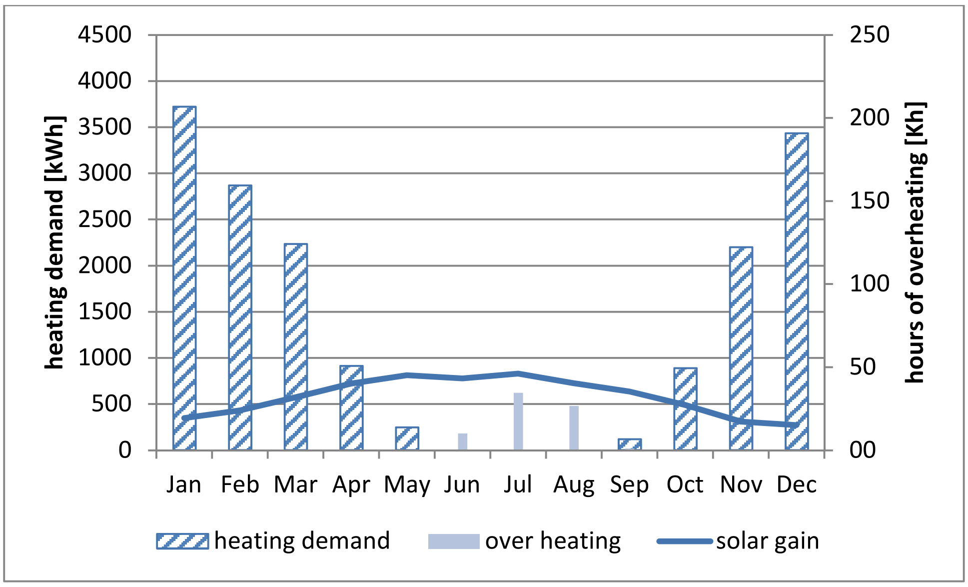


Figure 23, monthly heating demand and solar gains in kWh, overheating in Kh of scenario #3.2

In the following Table 10 the OI3 indicator of the building elements are listed. The values of the building elements are the impact of only the materials used for retrofitting.

Table 19, environmental indicator of scenario #3.2

exterior wall				180 m²
$PEC_{n.r}$ [MJ per m²]	148.3400	0	points	
GWP [kg CO2 eq. per m²]	6.2538	28	points	
AP [kg SO2 eq. per m²]	0.0224	0	points	
		9	points per m²	1,620 points

interior wall				40 m²
$PEC_{n.r}$ [MJ per m²]	318.2800	0	points	
GWP [kg CO2 eq. per m²]	24.0153	37	points	
AP [kg SO2 eq. per m²]	0.0695	0	points	
		12	points per m²	480 points

exterior slab				220 m²
$PEC_{n.r}$ [MJ per m²]	971.4600	47	points	
GWP [kg CO2 eq. per m²]	84.3900	67	points	
AP [kg SO2 eq. per m²]	0.2398	12	points	
		42	points per m²	9,240 points

roof				310 m²
$PEC_{n.r}$ [MJ per m²]	556.9600	6	points	
GWP [kg CO2 eq. per m²]	-21.9125	14	points	
AP [kg SO2 eq. per m²]	0.1588	0	points	
		7	points per m²	2,170 points

total OI3 points	13,510 points
OI3 points per m²	**18 points**

Table 20, construction costs according ÖNORM 1801-1 of scenario #3.2

2	BWR	building shell					
	2E	vertical building construction					
		2E.02	interior wall construction				
			porotherm brick	€ 45.51	x 40 m²	= €	1,820.40
3	BWT	building engineering				€	-
4	BWA	building finishing					
		4B.01	roof membrane				
			roof tile	€ 34.24			
			isover insulation	€ 25.39			
				€ 59.63	x 310 m²	= €	18,485.30
	4C	facade finishing					
		4C.01	facade paneling				
			silicone resin plasters	€ 15.94			
			insulation panel	€ 49.40			
				€ 65.34	x 180 m²	= €	11,761.20
		4C.02	facade openings				
			remove window	€ 33.80			
			window installation	€ 11.89			
				€ 45.69	x 11 pcs	= €	502.59
			window	€ 960.00	x 19 pcs	= €	18,240.00
			remove door	€ 95.80			
			entrance door	€ 1,645.00			
			door installation	€ 11.89			
				€ 1,752.69	x 2 pcs	= €	3,505.38
	4D	interior finishing					
		4D.01	floor covering				
			polystyrol	€ 16.69			
			polyethylene film	€ 1.33			
			cement screed	€ 14.60			
			parquet	€ 80.00			
				€ 112.62	x 220 m²	= €	24,776.40
					balance	**€**	**79,091.27**

				balance			**€**	**79,091.27**
4D.02	exterior wall finishing							
	lime-gypsum plasters	€	14.01	x	50 m²	=	€	700.50
4D.03	ceiling finishing							
	polystyrol	€	16.69	x	220 m²	=	€	3,671.80
	lime-gypsum plasters	€	14.01	x	80 m²	=	€	1,120.80
4D.04	doors and windows							
	door	€	270.00					
	door installation	€	4.30					
		€	274.30	x	4 pcs	=	€	1,097.20
4D.05	interior wall finishing							
	lime-gypsum plasters	€	14.01	x	80 m²	=	€	1,120.80
			total construction costs				**€**	**86,802.37**

Table 21, environmental impact values, absolute and per m² and eco-costs of scenario #3.2

absolute values

$PEC_{n.r}$	425,811	MJ			
GWP	13,859	kg CO_2	€ 135/ 1,000 kg CO	€	1,870.97
AP	109	kg SO_2	€ 8.25/ kg SO2	€	899.25
30 years of heating	19,455	kg CO_2	€ 135/ 1,000 kg CO	€	2,626.41
			total eco-costs	**€**	**5,396.63**

values per m² living area

$PEC_{n.r}$	2,241	$MJ.m^{-2}$			
GWP	73	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	9.85
AP	0.57	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	4.73
30 years of heating	102	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	13.82
			total eco-costs per m²	**€**	**28.40**

The construction costs for the retrofit and the extension are listed in Table 20 and are estimated to EUR 72,866.11 The annual heating demand of 16,628 kWh covered by district heating biomass over the period of 30 years translates to 19,455 kg CO2 and a present value of EUR 44,593.13 costs for heating.

The total cost estimation for this scenario including the eco-costs, the present value and the construction costs of heating is at EUR 122,855.87

Summary of scenario #3.2

net floor area	189	m²
envelope area	779	m²
glazing area	29	m²
annual heating demand	16,628	kWh
overheating	72	Kh
OI3 grading	18	points
estimated costs	122,855.87	EUR

3.1.6 Scenario #4

The area of the thermal envelope for scenario #4 sums up to 603.6 m² and 7.1 % of the envelope is transparent. The net living area is 239.9 m² (gross: 288.3 m²) and the net volume is 618.94 m³ (gross: 965.81 m³).

The output of the energy certificate created in ArchiPhysik shows an annual heating demand of 26 kWh.m^{-2} as seen in Figure 24. The monthly heating demand simulated from EnergyPlus is displayed in Figure 25. In one year this scenario shows an annual heating demand of 17,462 kWh, 494 Kh of overheating and 10,904 kWh solar gains through windows. The peak demand is simulated for the month of January with 4,189 kWh and solar gains of 529 kWh. The highest solar gains are in July with 1,264 kWh and 208 Kh of overheating.

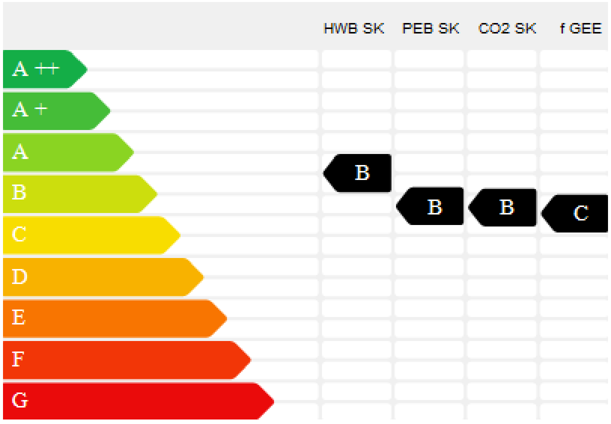


Figure 24, energy certificate of scenario #4

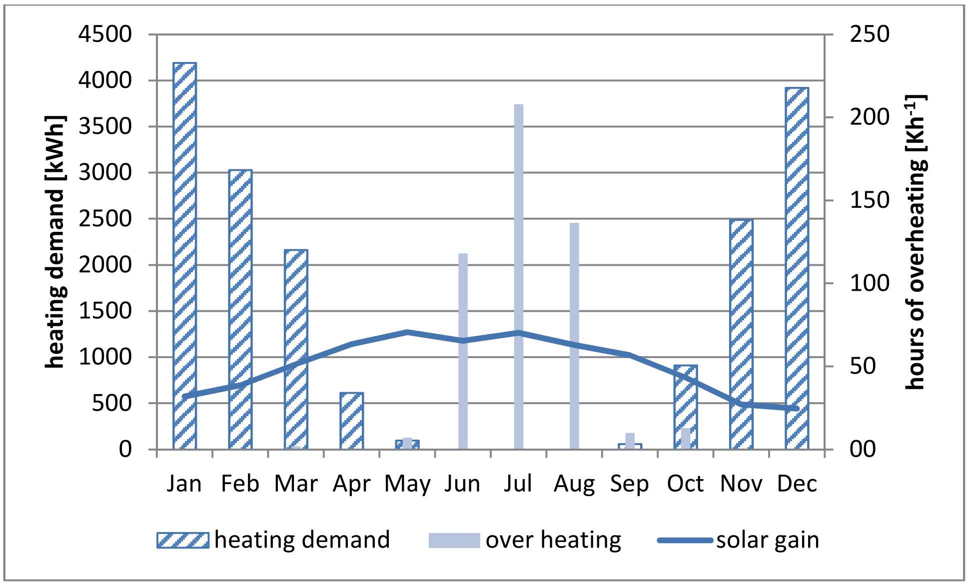


Figure 25, monthly heat demand of scenario #4 in kWh

In the following Table 22 the OI3 indicator of the building elements are listed. The values of the building elements are the impact of only the materials used for retrofitting.

Table 22, environmental indicator of scenario #4

exterior wall				190 m²
$PEC_{n.r}$ [MJ per m²]	909.7700	41	points	
GWP [kg CO2 eq. per m²]	59.2862	55	points	
AP [kg SO2 eq. per m²]	0.1804	0	points	
		32	points per m²	6,080 points

interior wall 12cm				110 m²
$PEC_{n.r}$ [MJ per m²]	318.2800	0	points	
GWP [kg CO2 eq. per m²]	24.0153	37	points	
AP [kg SO2 eq. per m²]	0.0695	0	points	
		12	points per m²	1,320 points

interior wall 25 cm				70 m²
$PEC_{n.r}$ [MJ per m²]	593.8900	9	points	
GWP [kg CO2 eq. per m²]	45.8488	48	points	
AP [kg SO2 eq. per m²]	0.1312	0	points	
		19	points per m²	1,330 points

slabs				450 m²
$PEC_{n.r}$ [MJ per m²]	1639.1500	100	points	
GWP [kg CO2 eq. per m²]	116.6030	83	points	
AP [kg SO2 eq. per m²]	0.3810	68	points	
		84	points per m²	37,800 points

roof				180 m²
$PEC_{n.r}$ [MJ per m²]	747.6000	25	points	
GWP [kg CO2 eq. per m²]	-11.1505	19	points	
AP [kg SO2 eq. per m²]	0.2069	0	points	
		15	points per m²	5,760 points
			total OI3 points	52,290 points
			OI3 points per m²	**49 points**

Table 23, construction costs according ÖNORM 1801-1 of scenario #4

2	BWR	building shell						
	2D	horizontal building construction						
		2D.01	slab construction					
			reinforced concrete	€	29.01	x 300 m²	= €	8,703.00
			timber wood	€	7.49	x 150 m²	= €	1,123.50
		2D.02	stair construction					
			reinforced concrete	€	29.01	x 9 m²	= €	246.59
		2D.03	roof construction					
			timber wood	€	2.43	x 180 m²	= €	437.40
	2E	vertical building construction						
		2E.01	exterior wall construction					
			porotherm brick	€	81.67	x 230 m²	= €	18,784.10
		2E.02	interior wall construction					
			porotherm brick	€	45.51	x 110 m²	= €	5,006.10
			porotherm brick	€	59.52	x 70 m²	= €	4,166.40
3	BWT	building engineering					**€**	**-**
4	BWA	building finishing						
	4B	roof finishing						
		4B.01	roof membrane					
			roof tile	€	34.24			
			isover insulation	€	25.39			
			isover insulation	€	47.83			
			isocell vapor barrier	€	3.60			
			gypsum plaster board	€	14.87			
				€	125.93	x 180 m²	= €	22,667.40
	4C	facade finishing						
		4C.01	facade paneling					
			silicone resin plasters	€	15.94			
			insulation panel	€	49.40			
				€	65.34	x 230 m²	= €	15,028.20
						balance		**€ 76,162.69**

					balance			**€ 76,162.69**
	4C.02	**facade openings**						
		window	€	960.00				
		window installation	€	11.89				
			€	971.89	x	12 pcs	= €	11,662.68
		entrance door	€	1,645.00				
		door installation	€	11.89				
			€	1,656.89	x	1 pcs	= €	1,656.89
4D	interior finishing							
	4D.01	**floor covering**						
		polystyrol	€	16.69				
		polyethylene film	€	1.33				
		cement screed	€	14.60				
			€	32.62	x	300 m^2	= €	9,786.00
		parquet	€	80.00	x	245 m^2	= €	19,600.00
		tiles	€	43.03	x	55 m^2	= €	2,366.65
	4D.02	**exterior wall finishing**						
		lime-gypsum plasters	€	14.01	x	230 m^2	= €	3,222.30
	4D.03	**ceiling finishing**						
		lime-gypsum plasters	€	14.87	x	450 m^2	= €	6,691.50
		polystyrol	€	16.69	x	300 m^2	= €	5,007.00
		polystyrol	€	38.27	x	150 m^2	= €	5,740.50
		gypsum plaster board	€	14.87	x	150 m^2	= €	2,230.50
	4D.04	**doors and windows**						
		door	€	270.00				
		door installation	€	4.30				
			€	274.30	x	11 pcs	= €	3,017.30
	4D.05	**interior wall finishing**						
		lime-gypsum plasters	€	14.01	x	360 m^2	= €	5,043.60
					total construction costs			**€ 152,187.61**

Table 24, environmental impact values, absolute and per m² of scenario #4

absolute values

$PEC_{n.r}$	1,121,600	MJ			
GWP	67,600	kg CO_2	€ 135/ 1,000 kg CO	€	9,123.26
AP	260	kg SO_2	€ 8.25/ kg SO2	€	2,143.27
30 years of heating	20,400	kg CO_2	€ 135/ 1,000 kg CO	€	2,758.17
			total eco-costs	**€**	**14,024.71**

values per m² living area

$PEC_{n.r}$	4,670	$MJ.m^{-2}$			
GWP	282	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	38.01
AP	1.08	kg $SO_2.m^{-2}$	€ 8.25/ kg SO2	€	8.93
30 years of heating	85	kg $CO_2.m^{-2}$	€ 135/ 1,000 kg CO	€	11.49
			total eco-costs per m²	**€**	**58.44**

The construction costs for the retrofit and the extension are listed in Table 23 and are estimated to EUR 152,187.61 The annual heating demand of 17,462 kWh covered by district heating biomass over the period of 30 years translates to 20,400 kg CO2 and a present value of EUR 46,830.25 costs for heating.

The total cost estimation for this scenario including the eco-costs, the present value and the construction costs of heating is at EUR 213,042.57

Summary of scenario #4

net floor area	240	m²
envelope area	604	m²
glazing area	43	m²
annual heating demand	17,462	kWh
overheating	494	Kh
OI3 grading	49	points
estimated costs	213,042.57	EUR

Table 25, summary of results of all six scenarios

	#1		#2.1		#2.2		#3.1		#3.2		#4	
net floor area	119	m^2	119	m^2	119	m^2	189	m^2	189	m^2	240	m^2
envelope area	463	m^2	463	m^2	511	m^2	689	m^2	779	m^2	604	m^2
glazing area	15	m^2	15	m^2	15	m^2	29	m^2	29	m^2	43	m^2
annual heating demand	19,345	kWh	10,732	kWh	11,044	kWh	16,212	kWh	16,628	kWh	17,462	kWh
overheating	118	Kh	79	Kh	72	Kh	80	Kh	72	Kh	494	Kh
OI3 grading	-	points	21	points	18	points	21	points	18	points	49	points
$PEC_{n.r}$	-	MJ	196,824	MJ	261,111	MJ	318,423	MJ	425,811	MJ	1,121,600	MJ
GWP	-	kg CO_2	14,378	kg CO_2	8,464	kg CO_2	23,403	kg CO_2	13,859	kg CO_2	67,600	kg CO_2
AP	-	kg SO_2	43	kg SO_2	67	kg SO_2	69	kg SO_2	109	kg SO_2	260	kg SO_2
30 years of heating	185,133	kg CO_2	12,556	kg CO_2	12,922	kg CO_2	18,969	kg CO_2	19,455	kg CO_2	20,400	kg CO_2
estimated costs	71,551.51	EUR	73,913.11	EUR	83,193.66	EUR	108,941.04	EUR	122,855.87	EUR	213,042.57	EUR

Chapter 4

Discussion

4.1 Overview

Unlike in the previous section, the upcoming comparison and discussion will show the six scenarios next to each other in the three categories (1) thermal performance, (2) environmental impact and (3) cost estimation.

4.2 Thermal Performance

The difference in U-values after the retrofit mirrors the results of the annual heating demand of the scenarios as seen in Table 26. According to the energy certificate from ArchiPhysik House 1950 as represented in scenario #1 shows the worst thermal performance with an annual heating demand of 238 kW.m^{-2}. Such a result is common for old and not retrofitted buildings. The simulated annual heating demand of EnergyPlus amounts to 19,345 kWh as presented in Figure 26.

Table 26, annual heating demand per m² from energy certificate of all scenarios

	annual heating demand per m² [kWh.m^{-2}]
Scenario #1	238
Scenario #2.1	49
Scenario #2.2	88
Scenario #3.1	41
Scenario #3.2	76
Scenario #4	26

By adding thermal insulation to the external building envelope and replacing windows and doors of House 1950 as implemented in scenario #2.1 and #2.2, the standards of a low energy building of category B and C according to ÖNORM H 5055 are achieved. These adjustments cut the original heating demand by almost 50 % to 10,732 kWh and 11,044 kWh per year as seen in Table 27.

The simulated results of the annual heating demand in Figure 26 differ from the values generated from ArchiPhysik, but show similar trends. Comparing the energy certificates, the retrofit variations #2.1 and #2.2 show a significant difference due to the calculation method of ArchiPhysik. Therefore, the simulated results from EnergyPlus will be used for further comparisons.

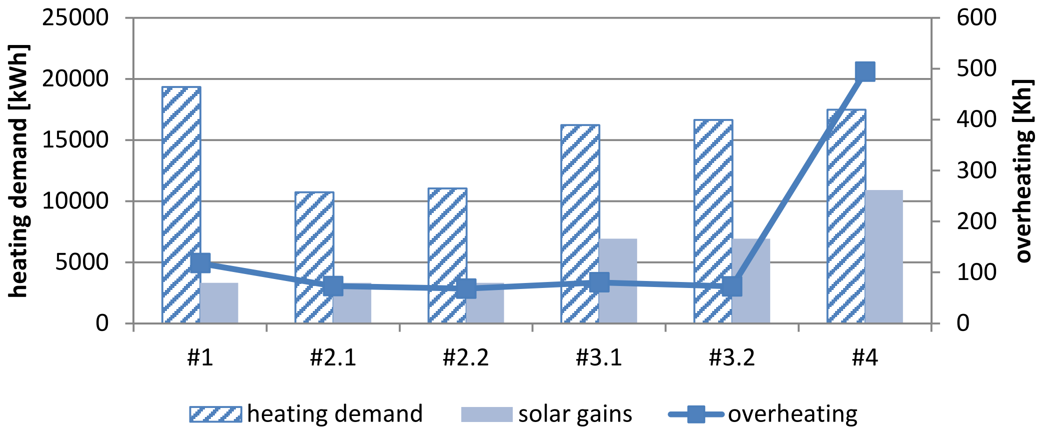


Figure 26, annual heating demand and solar gains in kWh, overheating in Kh of all scenarios

Table 27, annual heating demand per m² and absolute values from EnergyPlus of all scenarios

	annual heating demand [kWh]	annual heating demand per m² [kWh.m^{-2}]
Scenario #1	19,345	163
Scenario #2.1	10,732	90
Scenario #2.2	11,044	93
Scenario #3.1	16,212	86
Scenario #3.2	16,628	88
Scenario #4	17,462	73

In scenarios #3.1 and #3.2 additional living space has been created and the same U-Values as in the previous scenarios have been used. By increasing the living area from 119 m² to 189 m² the heating demand increases almost proportionally to the added square meters. Due to only small differences in the results per square meter, again the standards of a low energy building of category B and C according to ÖNORM H 5055 are achieved. Whereas House 2014, with 26 kWh.m^{-2}, misses to achieve category A by a single kilowatt-hour per square meter.

Although the net floor area of House 2014 amounts to 240 m², 50 m² more than House 1950+, only 834 kWh more are necessary for heating this two-story building annually. The better performance is also visible as scenario #4, with 73 kWh.m^{-2}, has the lowest annual heating demand per square meter out of all the six scenarios as seen in Table 27. In both scenarios #2 and #3 the first retrofit variation, insulating the ceiling to the attic, proves more efficient than the second variation of insulating the roof.

The heating demand, the solar gains and the overheating are shown in Figure 26. After retrofitting the annual heating demand is reduced by almost 50 %. Since these scenarios have the same solar gains and window areas, the additional insulation is the reason for the improvement.

Table 28, overheating in Kh, solar gains in kWh and area of glazing of all scenarios

	overheating [Kh]	solar gains [kWh]	transparent area [m²]
Scenario #1	118	3,319	14.6
Scenario #2.1	73	3,319	14.6
Scenario #2.2	68	3,319	14.6
Scenario #3.1	80	6,929	29.1
Scenario #3.2	72	6,929	29.1
Scenario #4	494	10,905	43.0

As the solar gains increase the more the rooms are overheating, which is the case for scenarios #3.1, #3.2 and #4. For the extension the amount of windows is doubled, which results in also twice as many solar gains and more overheating as in the previous scenarios. With the largest area of window glass, House 2014 shows the most solar gains and the worst overheating performance of all the scenarios. This is due to the south orientation of the majority of the windows. This time in both scenarios #2 and #3 the second variation, which encloses more volume in the thermal envelope than the first variation, performs slightly better and overheats less than the other scenarios. It has to be pointed out that for the sake of comparison the building simulations of all the scenarios had the same ventilation assumption. The overheating of House 2014 could have easily been reduced by increasing the ventilation rate during the night time, to allow the rooms to cool down.

By renovating the old parts of the barn, new additional living space is created, but also more rooms that require heating are generated. Yet any scenario other than the original House 1950 requires less energy for heating, proving how beneficial the improvement of an old building can be. The two renovation variations are only showing minimal differences, but the first renovation variation has a slightly better thermal performance.

Last but not least, House 2014 was designed with double the size of House 1950, yet requires less energy for heating than the original or extended version of the old building. That aside, some rooms need special attention for thermal comfort. Especially rooms facing south tend to overheat easily if not prevented with certain countermeasures.

4.3 Environmental Impact

The outcome of the OI3 calculations is presented in Table 29. The results are represented as points and are actually evaluating the construction materials per square meter of the thermal envelope. Therefore, the retrofit variations in scenario #2 and #3 have the same results, since the same materials have been used in the individual variations. Out of these two variations, with 18 points the second variation has a slightly lower impact than the first. Since House 2014 in scenario #4 requires different materials like the structural parts such as reinforced concrete, it has a significantly higher environmental impact than the other scenarios.

Table 29, OI3 indicator points of all scenarios

	OI3 Points
Scenario #1	0
Scenario #2.1	21
Scenario #2.2	18
Scenario #3.1	21
Scenario #3.2	18
Scenario #4	49

Since the point system is not revealing any information on the absolute quantities of greenhouse gases, a closer look at the values of the materials will help clarifying this matter. Table 30 and Table 31 show the environmental impact of the single projects in absolute values and values per square meters.

Table 30, OI3 indicator, absolute values for all scenarios

	$PEC_{n.r}$ [MJ]	GWP [kg CO_2]	AP [kg SO_2]
Scenario #2.1	196,824	14,378	43
Scenario #2.2	261,100	8,464	67
Scenario #3.1	318,423	23,403	69
Scenario #3.2	425,811	13,859	109
Scenario #4	1,121,625	67,580	260

As no surprise House 2014 has the largest environmental impact of all scenarios. Comparing the two retrofit variations, the roof-variations have 33 % higher non-renewable energy source requirements and 57 % higher acidification potential than the ceiling-variations. The global warming potential is the only factor which is opposite, since the second variations have 41 % less carbon dioxide than the first variations. Dividing the absolute values by the net floor area of each scenario does not change the overall outcome. Scenario #4 still has the highest impact and the two variations still have the same trend as seen in Table 31.

Table 31, OI3 indicator, values per m² for all scenarios

	$PEC_{n.r}$ per m² [$MJ.m^{-2}$]	GWP per m² [$kg\ CO_2.m^{-2}$]	AP per m² [$kg\ SO_2.m^{-2}$]
Scenario #2.1	1,640	120	0.36
Scenario #2.2	2,176	71	0.56
Scenario #3.1	1,676	123	0.36
Scenario #3.2	2,241	73	0.57
Scenario #4	4,673	282	1.08

Another environmental impact is generated by the heating sources. As seen in Table 32, by a landslide scenario #1 has the biggest emission of carbon dioxide of 185,133 kg CO_2 generated through heating with natural gas over a period of 30 years. Changing to biomass heating creates a significantly lower impact as seen in the other five scenarios. The retrofit and change of heating source would reduce the CO_2 emission of 30 years by 93 % to 12,556 and 12,922 kg CO_2. Although House 2014 has 50 m² more living area, it only has a 5-7 % increase compared to House 1950+. Whereas the additional 70 m² in the variations of scenario #3 have an increase of 34 % compared to the variations of scenario #2, which once again shows how well the newly built building performs.

Table 32, heating fuel of the next 30 years translated to kg CO_2 of all scenarios

	CO_2 footprint of heating [kg CO_2]
Scenario #1	185,133
Scenario #2.1	12,556
Scenario #2.2	12,922
Scenario #3.1	18,969
Scenario #3.2	19,455
Scenario #4	20,431

As expected building an entirely new house has a greater environmental impact than adding an extension or renovating, due to the solely reason of requiring more materials to build. Nevertheless, choosing environmental friendly components for new housing projects can further reduce the footprint.

In perspective to long term impacts, especially created by the sources of heating, it is very advisable to at least retrofit an old building. This measure will reduce the carbon footprint for 30 years of heating by more than 90 %. Of course House 2014, which is fulfilling the current building standards, also shows a significant improvement compared to the original House 1950.

It is still unclear, which retrofit variation has better results, since the first variations, insulating the ceiling to the attic, has lower non-renewable energy source requirements and acidification potential, whereas the second variation, insulating the roof, has lower global warming potential and better overall results in points. The final conclusion should also consider the cost estimation of the variations.

4.4 Cost Estimation

Applying the eco-costs of emissions as suggested by TU Delft these greenhouse gases can be translated to a monetary value. The estimated prevention costs for 1,000 kg of carbon dioxide amounts to EUR 135.00 and EUR 8.25 for each kilogram of sulphur dioxide (TU Delft, 2012).

The total costs for emissions from the construction and the carbon dioxide produced from 30 years of heating are displayed in Table 33. Although scenario #1 only has the emissions from heating as eco-costs, it still shows the highest amount of all the scenarios, which also include the construction materials. Scenario #4 again has the second highest values, since it requires more construction elements than the retrofit variation. Comparing the two variations, the second version has lower eco-costs, although it has higher heating demands. The driving factor in this case is that the global warming potential was significantly lower than in the first scenarios.

Table 33, eco-costs of emissions in EUR of all scenarios

	eco-costs of emissions [EUR]	eco-costs of emissions per m² [EUR]
Scenario #1	24,992.94	208.27
Scenario #2.1	3,990.87	33.26
Scenario #2.2	3,439.86	28.67
Scenario #3.1	6,289.40	33.10
Scenario #3.2	5,396.63	28.40
Scenario #4	14,024.71	58.44

The estimated construction costs of all scenarios are shown in Table 34. Since building a new house requires more materials than simply adding a retrofitted extension, it is no surprise that with EUR 152,187.61 scenario #4 has the highest material costs. For the two retrofit variations, the cost estimation is the final factor for comparison. Since the roof has a greater area than the ceiling to the attic, the second variations also need more material for the retrofit, which makes them more expensive.

Table 34, construction cost of retrofit, extension and new construction of all scenarios

	construction costs [EUR]	construction costs per m² [EUR]
Scenario #1	0.00	0.00
Scenario #2.1	41,141.79	342.85
Scenario #2.2	50,134.89	417.79
Scenario #3.1	59,173.41	311.44
Scenario #3.2	72,866.11	383.51
Scenario #4	152,187.61	634.12

The heating expenses of the next 30 years would amount to the values listed in Table 35. The renovated House 1950 with retrofitting the ceiling to the attic had the lowest annual heating demand and it therefore also has the lowest heating expenses. This would be a saving of EUR 17,778.12 over 30 years of heating. Also the extended variation show lower expenses than the original building, but due to the larger heated area, the saving is less significant. The comparison between House 1950 and House 2014 also has to be pointed out. A 60 year old building with no insulation and 120 m² living space accumulates almost the same amount of expenses as a newly built building with double the living space.

Table 35, present value of heating expenses of the next 30 years of all scenarios

	present value of heating expenses [EUR]	present value of heating expenses per m² [EUR]
Scenario #1	46,558.57	387.99
Scenario #2.1	28,780.45	239.84
Scenario #2.2	29,618.91	246.82
Scenario #3.1	43,478.23	228.83
Scenario #3.2	44,593.13	234.70
Scenario #4	46,830.25	195.13

Overall building a new house is the more expensive investment compared to a simple renovation and extension of an existing family house. Although the savings in heating expenses do not entirely cover the expenses for construction, renovating is still recommended. When retrofitting an old building such as House 1950, the first retrofit variation, which insulates the ceiling to the attic, is advisable. Although this variation has a slightly greater impact on the environment, it minimizes the thermal envelope and is therefore more economical and has also a better heating performance. The second variation, which replaces the entire roof with insulation and new tiles, is only recommended, if the attic is actively used as additional living space and surplus values is generated.

Solely comparing the expenses and eco-costs for heating, it is once again clear that renovating an old building is very advisable. Since these positions correlate to the carbon footprint generated by heating, which are also based on the thermal performance, this result is no longer a surprise. As expensive House 2014 may be, it is clear that a sophisticated architectural design combined with modern sustainable materials has the overall lowest heating expenses per square meter.

Chapter 5

Conclusion

By thermally retrofitting an old building as House 1950, the annual heating demand can be reduced by 38 %. As a result the environmental impact of heating decreases as well. Especially if the obsolete heating system is exchanged by modern and sustainable technology, the carbon footprint for 30 years of heating can be reduced significantly by over 90 %. Simply comparing the investment options, any choice other than continuing with the status quo will result in a monetary loss. The total heating savings after a retrofit only amounts to approximately EUR 17,800.00 or EUR 150.00 per square meter, which hardly covers the expenses for renovation.

The newly designed building House 2014, with twice the size of the old building, requires less energy for heating than the old building or the extended version. Nevertheless, some zones need special attention to be comfortable during summer. Especially rooms facing south tend to overheat easily if not prevented with certain countermeasures.

As expected the new house has a greater environmental impact than adding an extension or renovating. For the long term impact of the existing building, especially created by heating, it is very advisable to at least retrofit the old building.

In the case of the projects examined in this thesis, building a new house is the more expensive investment compared to a simple renovation and extension of an existing family house. However, a sophisticated architectural design combined with modern sustainable materials features the overall lowest heating expenses per square meter.

This thesis is based on two existing buildings. The outcome does not specify that it may be the same or similar to other single family houses in central Europe. Nevertheless, taking other case studies into account would cover a wider range of results for the same region and the outcomes could be used for further comparison.

Burgenland is a region prone to flooding, Unterwart is no exception. In the simulations of this thesis the building elements are treated as they have not been affected by any past flooding due to the difficulty of measuring. In real life this would not be the case and wet building parts alter the thermal performance. Although some background research was performed within the range of this thesis, this specific issue was not addressed in the methodology for reasons of simplicity.

Future efforts should address the thermal performance during summer, as this is a common issue in Burgenland. The overheating in the simulated projects is unsatisfactory and improvements are still possible. Also interesting would be a comparison of different retrofit possibilities with alternative insulations. Aiming for the same thermal performance would still result in different ecological footprints and expenses.

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List of Abbreviations

AP .... acidification potential

BG .... boundary group

BWA............... Bauwerk-Ausbau

BWK............... Bauerwerkskosten

BWR............... Bauwerk-Rohbau

BWT .... Bauwerk-Technik

C .... future costs

°C .... degree celsius

$CO_2.kg^{-1}$.......... carbon dioxide per kilogram

EUR .... Euro

GWP .... global warming potential

h^{-1} .... per hour

i...................... interest rate / discount rate

IBO .... Österreichisches Institut für Bauen und Ökologie

$J.kg^{-1}.K^{-1}$ .... joule per kilogram kelvin

$kg.m^{-3}$............ kilogram per cubic meter

Kh .... kelvin hour

km.................. kilometer

kWh .... kilowatt-hour

LCA .... life cycle assessment

m .... meter

m² .... square meter

m³ .... cubic meter

$MJ.kg^{-1}$ .... megajoule per kilogram

n .... number of compound years

OIB .... Österreichisches Institut für Bautechnik

OI3 .... Ökoindex 3

$OI3_{KON}$ .... environmental indicator for 1 m² of a structure

OI_{AP} .... environmental indicator of acidification potential

OI_{GWP} .... environmental indicator of global warming potential

OI_{PECnr} .... environmental indicator of non-renewable primary energy content

ÖNORM .... Österreichische Normen

$PEC_{n.r.}$ .... non-renewable energy source requirement

PV.................. present value

$SO_2.kg^{-1}$ .... sulfur dioxide per kilogram

$W.m^{-1}.K^{-1}$........ watt per meter kelvin

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APPENDIX

A. Plans, sections and elevations

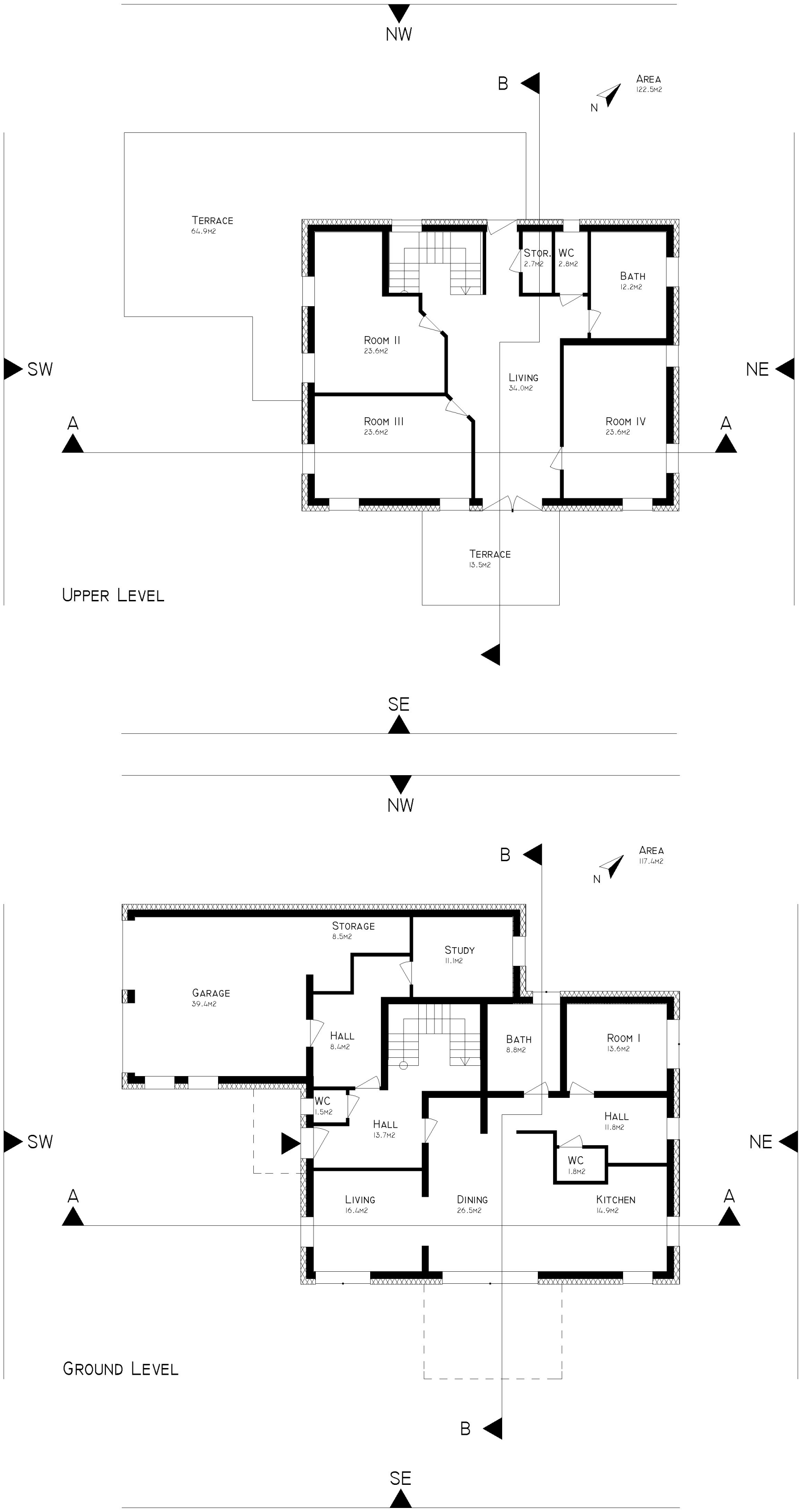


Figure 27, floor plan of House 2014 – ground and upper level, designed by the author

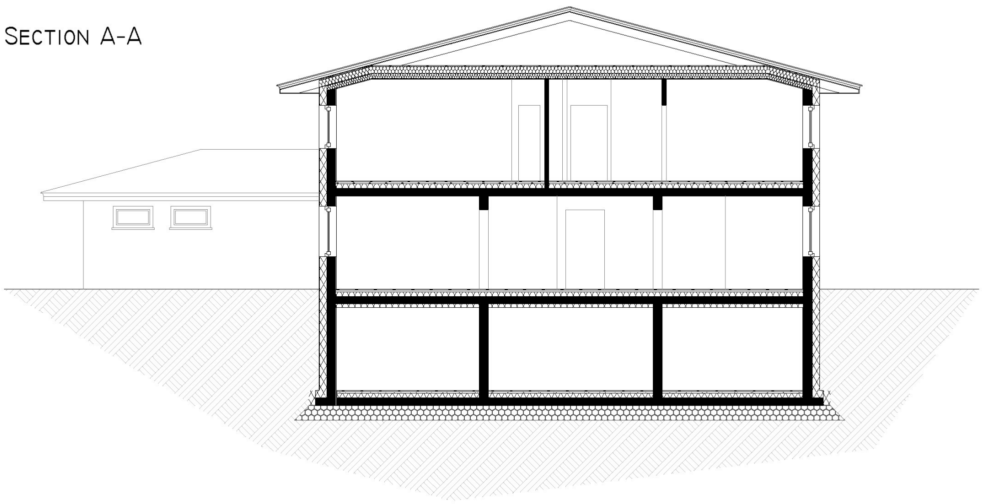


Figure 28, section of House 2014 – section A–A, designed by the author

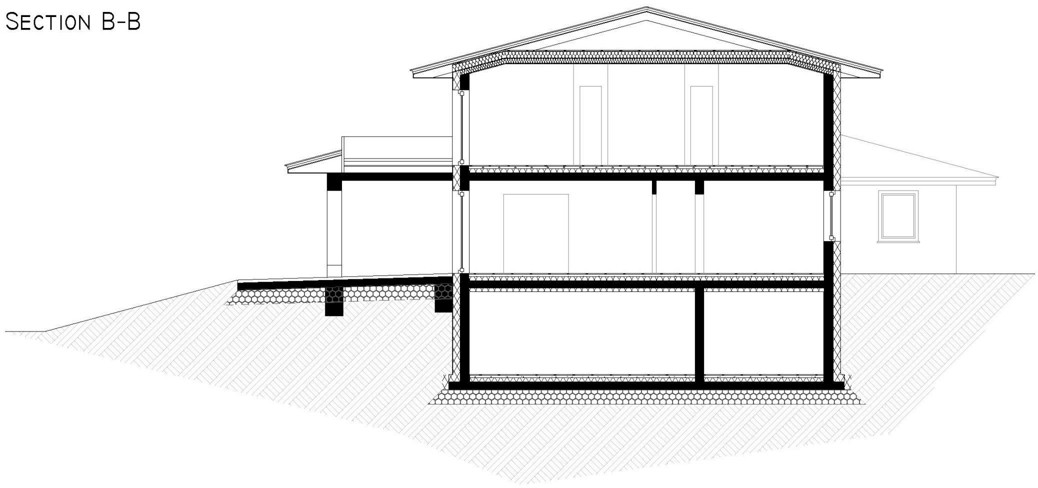


Figure 29, section of House 2014 – section B–B, designed by the author

Figure 30, elevation of House 2014 – South East, designed by the author

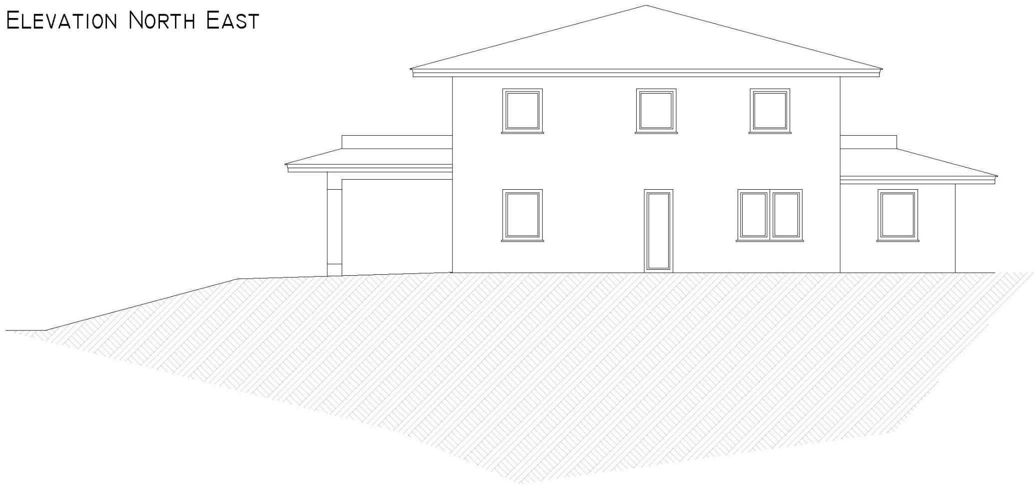


Figure 31, elevation of House 2014 – North East, designed by the author

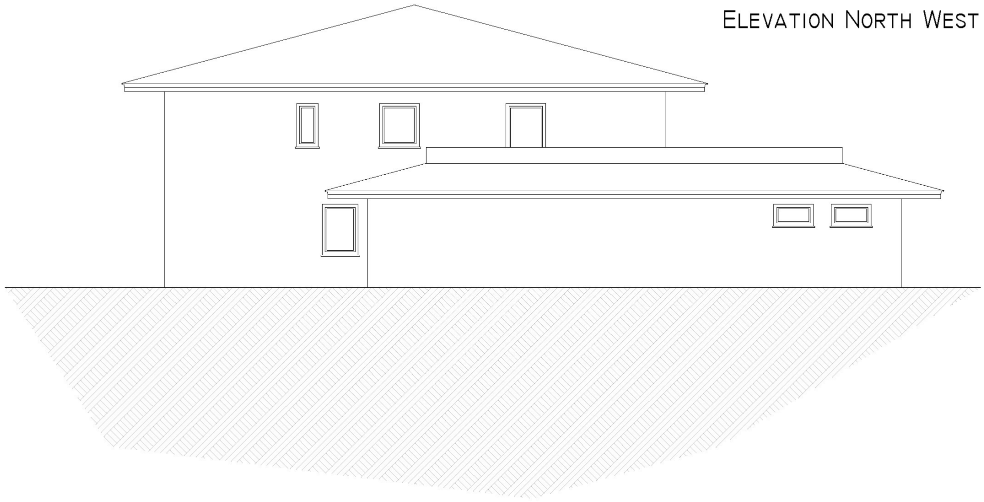


Figure 32, elevation of House 2014 – North West, designed by the author

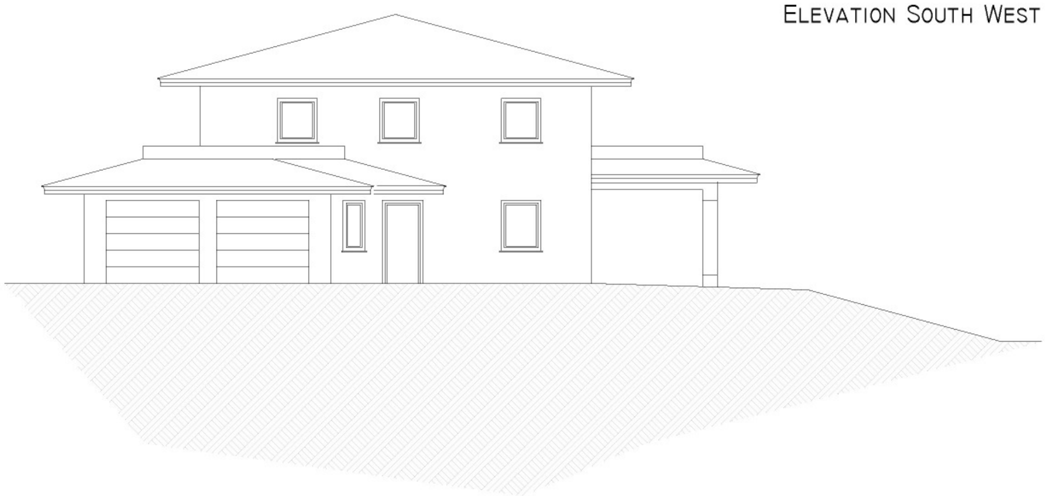


Figure 33, elevation of House 2014 – South West, designed by the author

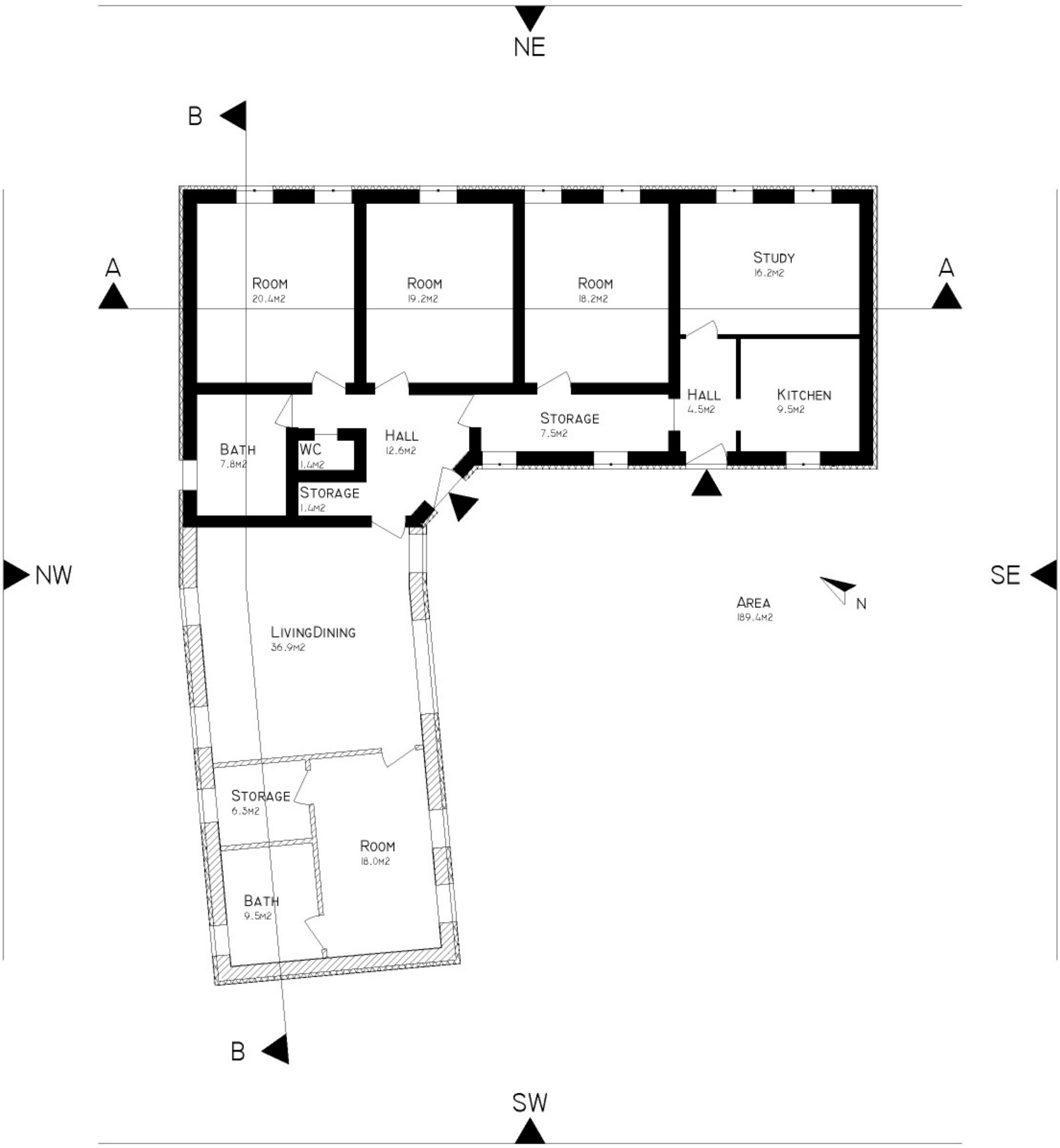


Figure 34, floor plan of House 1950+, designed by the author

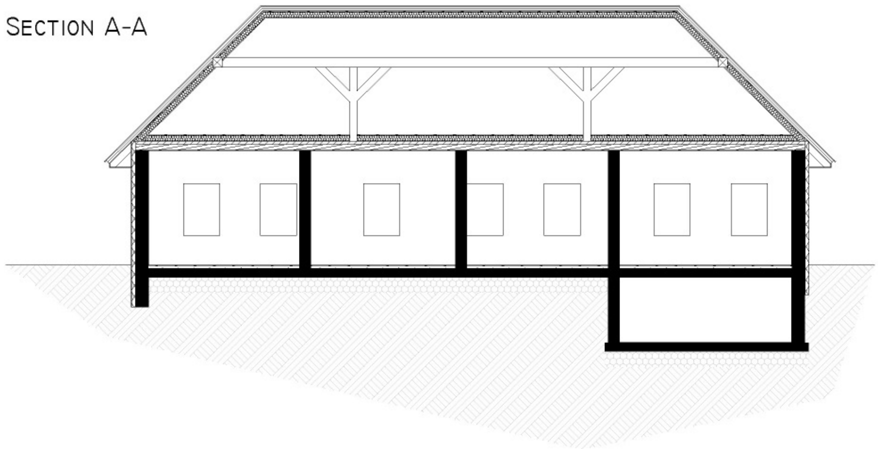


Figure 35, section of House 1950+ - section A–A, designed by the author

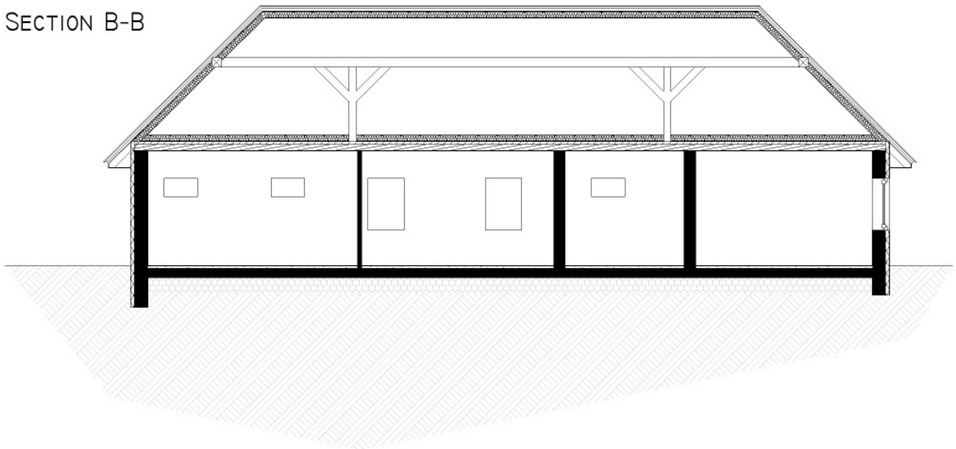


Figure 36, section of House 1950+ - section B–B, designed by the author

Figure 37, elevation of House 1950+ - North East, designed by the author

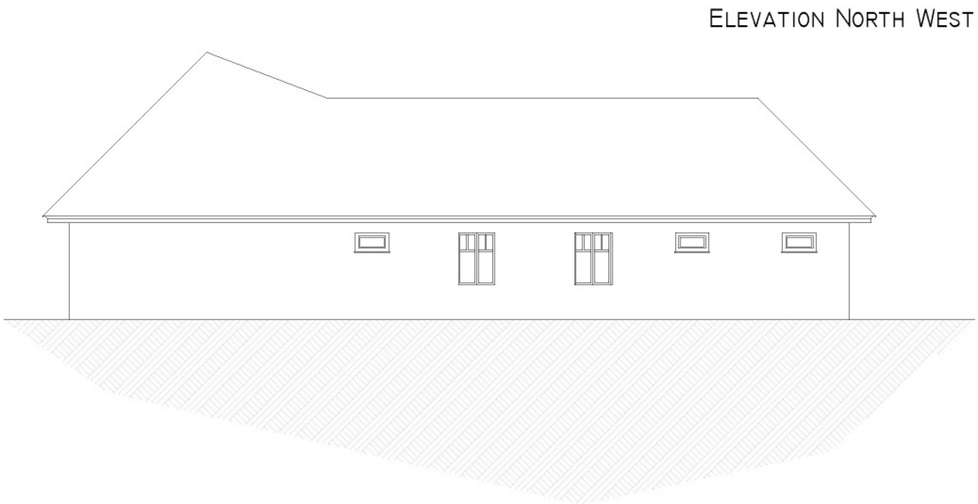


Figure 38, elevation of House 1950+ - North West, designed by the author

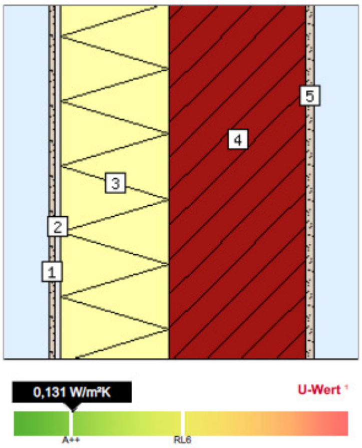
Figure 39, elevation of House 1950+ - South West, designed by the author

Figure 40, elevation of House 1950+ - South East, designed by the author

B. Building elements

new house - exterior wall

Wand: gegen Außenluft - nicht hinterlüftet



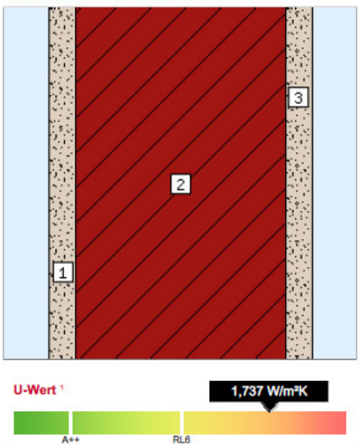
Nr.	Typ	**Schicht** (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch (Kleber mineralisch)	0,400	1,000	0,004	2
3		FLAPORplus Fassaden-Dämmplatte EPS-F	20,000	0,031	6,452	18
4		POROTHERM 25-38 N+F (natureplus)	25,000	0,259	0,965	38
5		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R'' (max. relativer Fehler: 0,0%) =			7,620 / 7,620	
		Bauteil	**47,100**		**7,620**	**64**

Masse	**249,1 kg/m²**
PEI n. e.	909,77 MJ/m²
GWP100	59,2862 kg CO_2/m²
AP	0,180375 kg SO_2/m²

Figure 41, attributes of building element: exterior wall

new house - interior wall 12cm

Wand: gegen Außenluft - nicht hinterlüftet



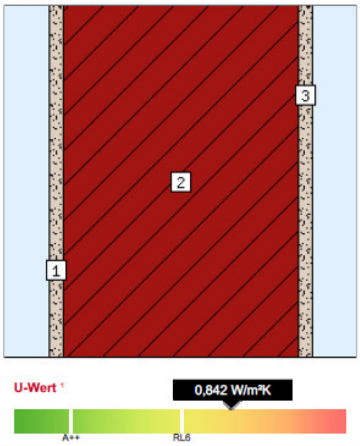
Nr.	Typ	**Schicht** (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
2		POROTHERM 12-50 N+F	12,000	0,340	0,353	17
3		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R'' (max. relativer Fehler: 0,0%) =			0,576 / 0,576	
		Bauteil	**15,000**		**0,576**	**24**

Masse	**135,0 kg/m²**
PEI n. e.	318,28 MJ/m²
GWP100	24,0153 kg CO_2/m²
AP	0,069507 kg SO_2/m²

Figure 42, attributes of building element: interior wall 12cm

new house - interior wall 25cm

Wand: gegen Außenluft - nicht hinterlüftet



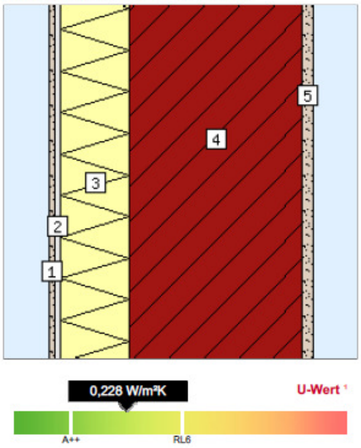
Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
2		POROTHERM 25-38 N+F (natureplus)	25,000	0,259	0,965	38
3		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R'' (max. relativer Fehler: 0,0%) =			1,188 / 1,188	
		Bauteil	**28,000**		**1,188**	**45**

Masse	**255,0 kg/m²**
PEI n. e.	593,89 MJ/m²
GWP100	45,8488 kg CO_2/m²
AP	0,131187 kg SO_2/m²

Figure 43, attributes of building element: interior wall 25cm

new house - interior wall to unheated

Wand: gegen Außenluft - nicht hinterlüftet



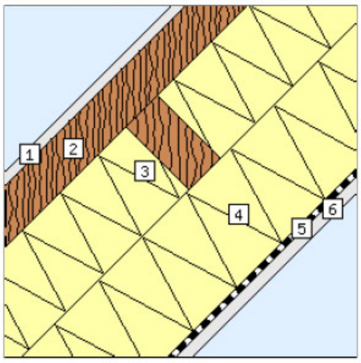
Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch (Kleber mineralisch)	0,400	1,000	0,004	2
3		FLAPORplus Fassaden-Dämmplatte EPS-F	10,000	0,031	3,226	9
4		POROTHERM 25-38 N+F (natureplus)	25,000	0,259	0,965	38
5		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R'' (max. relativer Fehler: 0,0%) =			4,394 / 4,394	
		Bauteil	**37,100**		**4,394**	**55**

Masse	**247,6 kg/m²**
PEI n. e.	761,42 MJ/m²
GWP100	53,0324 kg CO_2/m²
AP	0,158025 kg SO_2/m²

Figure 44, attributes of building element: interior wall to unheated space

new house - roof

Decke, Dach, 45°: Flach- oder Schrägdach gegen Außenluft - nicht hinterlüftet - Wärmestrom nach oben



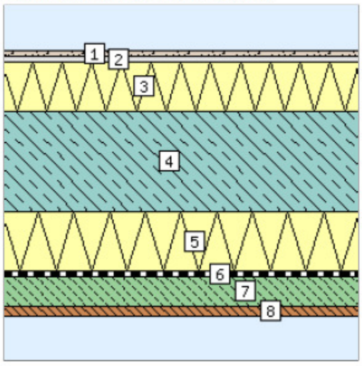
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		1, (Tondachziegel (2000 kg/m³))	1,270	1,000	0,013	7
2		Binderholz Massivholzplatte 3- oder mehrschichtig verle	6,000	0,120	0,500	15
3		*Inhomogen (Elemente längs bzw. normal zur Traufe)*	12,000			
		56,5 cm (90%) ISOVER-Zwischensparrenklemmfilz Inte	12,000	0,034	3,529	9
		6 cm (10%) Kaspar Greber Nadelstreifholz	12,000	0,120	1,000	3
4		ISOVER-Zwischensparrenklemmfilz Integra ZKF 1-035	14,000	0,034	4,118	12
5		ISOCELL AIRSTOP Dampfbremse	0,030	0,220	0,001	1
6		Gipskartonplatte (900 kg/m³)	1,500	0,250	0,060	4
		R_{si} / R_{se} =			0,100 / 0,040	
		R' / R'' (max. relativer Fehler: 2,3%) =			8,027 / 7,672	
		Bauteil	**34,800**		**7,849**	**51**

Masse	**78,3 kg/m²**
PEI n. e.	747,60 MJ/m²
GWP100	-11,1505 kg CO_2/m²
AP	0,206889 kg SO_2/m²

Figure 45, attributes of building element: roof

new house - interior floor

Boden: erdberührt - Wärmestrom nach unten



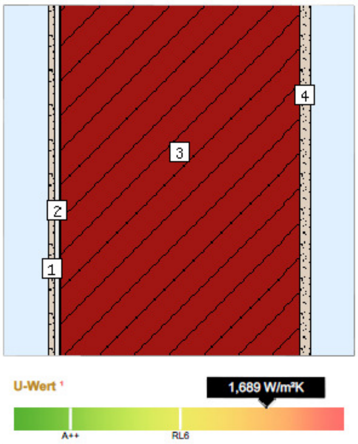
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch	0,400	1,000	0,004	2
3		FLAPORplus Fassaden-Dämmplatte EPS-F	10,000	0,031	3,226	9
4		Beton mit Bewehrung 2 % in WU-Qualität (2400 kg/m³)	20,000	2,500	0,080	70
5		FLAPORplus Fassaden-Dämmplatte EPS-F	12,000	0,031	3,871	11
6		Dampfbremse Polyethylen (PE)	0,010	0,500	0,000	0
7		RÖFIX 970 Zementestrich	6,000	1,600	0,038	11
8		Fertigparkett 2-Schicht	2,000	0,160	0,125	19
		R_{si} / R_{se} =			0,170 / 0,000	
		R' / R'' (max. relativer Fehler: 0,0%) =			7,516 / 7,516	
		Bauteil	**50,610**		**7,516**	**125**

Masse	**634,8 kg/m²**
PEI n. e.	1.639,15 MJ/m²
GWP100	116,6030 kg CO_2/m²
AP	0,381000 kg SO_2/m²

Figure 46, attributes of building element: interior floor

old house - exterior wall

Wand: gegen Außenluft - nicht hinterlüftet



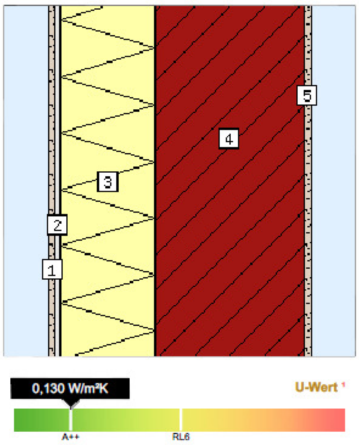
Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch	0,400	1,000	0,004	2
3		Klinker voll + Normalmauermörtel (2200 kg/m³)	35,000	0,900	0,389	167
4		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R" (max. relativer Fehler: 0,0%) =			0,592 / 0,592	
		Bauteil	**37,100**		**0,592**	**175**

Masse	**800,1 kg/m²**
PEI n. e.	3.088,13 MJ/m²
GWP100	187,5743 kg CO_2/m²
AP	0,308781 kg SO_2/m²

Figure 47, attributes of building element: exterior wall

old house - exterior wall*

Wand: gegen Außenluft - nicht hinterlüftet



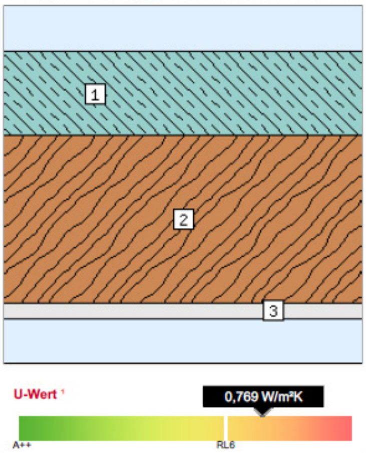
Nr.	Typ	Schicht (von innen nach aussen)	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Silikonharzputz	0,200	0,700	0,003	3
2		Kleber mineralisch	0,400	1,000	0,004	2
3		FLAPORplus Fassaden-Dämmplatte EPS-F	22,000	0,031	7,097	20
4		Klinker voll + Normalmauermörtel (2200 kg/m³)	35,000	0,900	0,389	167
5		Gipsputze (1300 kg/m³)	1,500	0,570	0,026	4
		R_{si} / R_{se} =			0,130 / 0,040	
		R' / R" (max. relativer Fehler: 0,0%) =			7,689 / 7,689	
		Bauteil	**59,100**		**7,689**	**195**

Masse	**803,4 kg/m²**
PEI n. e.	3.414,48 MJ/m²
GWP100	201,3327 kg CO_2/m²
AP	0,357951 kg SO_2/m²

Figure 48 attributes of building element: exterior wall after retrofit

old house - ceiling

Decke, Dach: Decke gegen unbeheizte Gebäudeteile - Wärmestrom nach oben



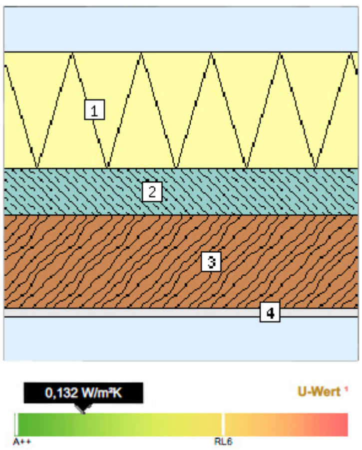
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Beton ohne Bewehrung in WU-Qualität(2400 kg/m³)	8,000	2,000	0,040	12
2		Holzboden, Vollholz	16,000	0,160	1,000	6
3		Gipskartonplatte (900 kg/m³)	1,500	0,250	0,060	4
		R_{si} / R_{se} =			0,100 / 0,100	
		R' / R'' (max. relativer Fehler: 0,0%) =			1,300 / 1,300	
		Bauteil	**25,500**		**1,300**	**22**

Masse	**313,5 kg/m²**
PEI n. e.	606,19 MJ/m²
GWP100	-139,0092 kg CO_2/m²
AP	0,190578 kg SO_2/m²

Figure 49, attributes of building element: ceiling

old house - ceiling*

Decke, Dach: Decke gegen unbeheizte Gebäudeteile - Wärmestrom nach oben



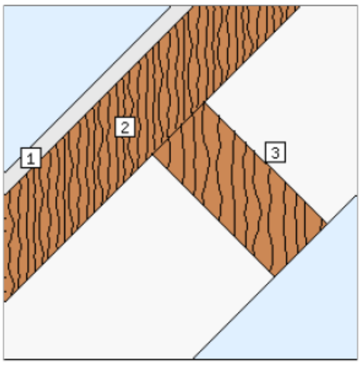
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		EPS Wärmedämmplatte WLG 032 20mm-300mm	20,000	0,032	6,250	18
2		Beton ohne Bewehrung in WU-Qualität(2400 kg/m³)	8,000	2,000	0,040	12
3		Holzboden, Vollholz	16,000	0,160	1,000	6
4		Gipskartonplatte (900 kg/m³)	1,500	0,250	0,060	4
		R_{si} / R_{se} =			0,100 / 0,100	
		R' / R'' (max. relativer Fehler: 0,0%) =			7,550 / 7,550	
		Bauteil	**45,500**		**7,550**	**40**

Masse	**316,5 kg/m²**
PEI n. e.	902,87 MJ/m²
GWP100	-126,5016 kg CO_2/m²
AP	0,235278 kg SO_2/m²

Figure 50, attributes of building element: ceiling after retrofit

old house - roof

Decke, Dach, 45°: Flach- oder Schrägdach gegen Außenluft - nicht hinterlüftet - Wärmestrom nach oben



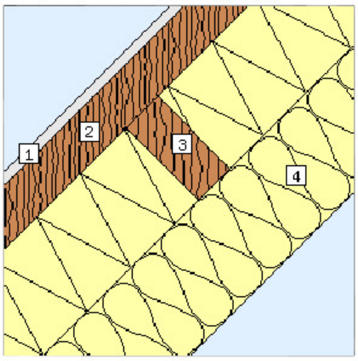
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Tondachziegel (2000 kg/m³)	1,270	1,000	0,013	7
2		Binderholz Massivholzplatte 3- oder mehrschichtig verle	6,000	0,120	0,500	15
3		*Inhomogen (Elemente längs bzw. normal zur Traufe)*	14,000			
		56,5 cm (90%) Luftschicht stehend, Wärmefluss horizon	14,000	0,778	0,180	0
		6 cm (10%) Kaspar Greber Nadelstreifholz	14,000	0,120	1,167	3
		R_{si} / R_{se} =			0,100 / 0,040	
		R' / R'' (max. relativer Fehler: 1,7%) =			0,878 / 0,849	
		Bauteil	**21,270**		**0,863**	**25**

Masse	**60,4 kg/m²**
PEI n. e.	434,04 MJ/m²
GWP100	-28,4339 kg CO_2/m²
AP	0,118103 kg SO_2/m²

Figure 51, attributes of building element: roof

old house - roof*

Decke, Dach, 45°: Flach- oder Schrägdach gegen Außenluft - nicht hinterlüftet - Wärmestrom nach oben



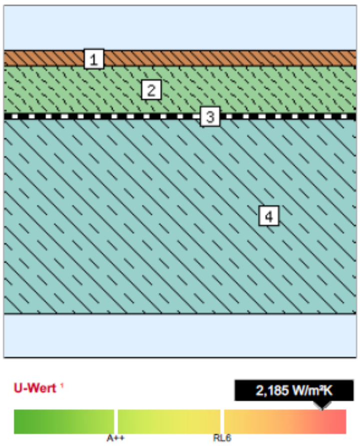
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Tondachziegel (2000 kg/m³)	1,270	1,000	0,013	7
2		Binderholz Massivholzplatte 3- oder mehrschichtig verle	6,000	0,120	0,500	15
3		*Inhomogen (Elemente längs bzw. normal zur Traufe)*	14,000			
		56,5 cm (90%) ISOVER-Zwischensparrenklemmfilz Inte	14,000	0,034	4,118	11
		6 cm (10%) Kaspar Greber Nadelstreifholz	14,000	0,120	1,167	3
4		ISOVER-Zwischensparrenklemmfilz Integra ZKF 1-035	14,000	0,034	4,118	12
		R_{si} / R_{se} =			0,100 / 0,040	
		R' / R'' (max. relativer Fehler: 2,4%) =			8,483 / 8,083	
		Bauteil	**35,270**		**8,283**	**48**

Masse	**65,9 kg/m²**
PEI n. e.	692,93 MJ/m²
GWP100	-14,6984 kg CO_2/m²
AP	0,203844 kg SO_2/m²

Figure 52, attributes of building element: roof after retrofit

old house - interior floor

Boden: erdberührt - Wärmestrom nach unten



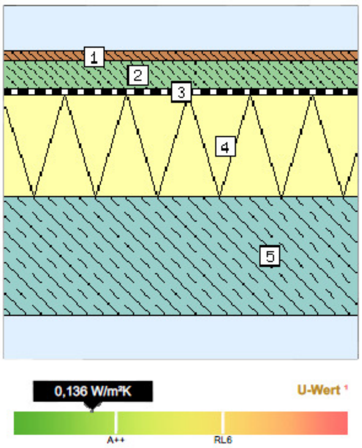
Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Parkett Massiv	2,000	0,160	0,125	19
2		RÖFIX 970 Zementestrich	6,000	1,600	0,038	11
3		Dampfbremse Polyethylen (PE)	0,010	0,500	0,000	0
4		Beton ohne Bewehrung in WU-Qualität(2400 kg/m³)	25,000	2,000	0,125	39
		R_{si} / R_{se} =		0,170 / 0,000		
		R' / R'' (max. relativer Fehler: 0,0%) =		0,458 / 0,458		
		Bauteil	**33,010**		**0,458**	**69**

Masse	**740,9 kg/m²**
PEI n. e.	823,12 MJ/m²
GWP100	78,1362 kg CO_2/m²
AP	0,217420 kg SO_2/m²

Figure 53, attributes of building element: interior floor

old house - interior floor*

Boden: erdberührt - Wärmestrom nach unten



Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Parkett Massiv	2,000	0,160	0,125	19
2		RÖFIX 970 Zementestrich	6,000	1,600	0,038	11
3		Dampfbremse Polyethylen (PE)	0,010	0,500	0,000	0
4		EPS Wärmedämmplatte WLG 032 20mm-300mm	22,000	0,032	6,875	20
5		Beton ohne Bewehrung in WU-Qualität(2400 kg/m³)	25,000	2,000	0,125	39
		R_{si} / R_{se} =		0,170 / 0,000		
		R' / R'' (max. relativer Fehler: 0,0%) =		7,333 / 7,333		
		Bauteil	**55,010**		**7,333**	**89**

Masse	**744,2 kg/m²**
PEI n. e.	1.149,47 MJ/m²
GWP100	91,8946 kg CO_2/m²
AP	0,266590 kg SO_2/m²

Figure 54, attributes of building element: interior floor after improvement

C. Activity schedules

Table 36, activity schedule of living room

	Time	Occupants	Equipment [W]
weekdays	00:00-07:00	0	10
	07:00-12:00	2	60
	12:00-17:00	4	200
	17:00-21:00	1	60
	21:00-22:00	2	60
	22:00-24:00	0	10
weekends	00:00-07:00	0	10
	07:00-12:00	4	150
	12:00-17:00	5	200
	17:00-23:00	4	150
	23:00-24:00	0	10

Table 37, activity schedule of bed room

	Time	Occupants	Equipment [W]
weekdays	00:00-06:00	1	0
	06:00-22:00	0	0
	22:00-24:00	1	60
weekends	00:00-08:00	1	0
	08:00-23:00	0	0
	23:00-24:00	1	60

Table 38, activity schedule of bath room

	Time	Occupants	Equipment [W]
weekdays	00:00-06:00	0	0
	06:00-07:00	1	60
	07:00-21:00	0	0
	21:00-22:00	1	60
	22:00-24:00	0	0
weekends	00:00-08:00	0	0
	08:00-09:00	1	60
	09:00-22:00	0	0
	22:00-23:00	1	60
	23:00-24:00	0	0

Table 39, activity schedule of kitchen

	Time	Occupants	Equipment [W]
weekdays	00:00-06:00	0	40
	06:00-07:00	2	540
	07:00-12:00	0	40
	12:00-13:00	3	1040
	13:00-19:00	0	40
	19:00-20:00	2	540
	20:00-24:00	0	40
weekends	00:00-08:00	0	40
	08:00-09:00	2	540
	09:00-13:00	0	40
	13:00-14:00	3	1040
	14:00-20:00	0	40
	20:00-21:00	2	540
	21:00-24:00	0	40

Table 40, activity schedule of study

	Time	Occupants	Equipment [W]
weekdays	00:00-10:00	0	10
	10:00-13:00	1	100
	13:00-14:00	0	10
	14:00-17:00	1	100
	17:00-24:00	0	10
weekends	00:00-08:00	0	10
	08:00-09:00	1	100
	09:00-21:00	0	10
	21:00-22:00	1	100
	22:00-24:00	0	10

D. Ground Heat Transfer

Field	Units	Obj1
NMAT: Number of materials		2
ALBEDO: Surface Albedo: No Snow		0,16
ALBEDO: Surface Albedo: Snow		0,4
EPSLW: Surface Emissivity: No Snow		0,94
EPSLW: Surface Emissivity: Snow		0,86
Z0: Surface Roughness: No Snow	cm	
Z0: Surface Roughness: Snow	cm	0,25
HIN: Indoor HConv: Downward Flow	W/m2-K	6,13
HIN: Indoor HConv: Upward	W/m2-K	9,26

Figure 55, input parameter: ground heat transfer slab - Materials

Field	Units	Obj1
RHO: Slab Material density	kg/m3	1900
RHO: Soil Density	kg/m3	1200
CP: Slab CP	J/kg-K	650
CP: Soil CP	J/kg-K	1200
TCON: Slab k	W/m-K	0,9
TCON: Soil k	W/m-K	1

Figure 56, input parameter: ground heat transfer slab - MatProps

Field	Units	Obj1
IYRS: Number of years to iterate		10
Shape: Slab shape		0
HBLDG: Building height	m	7,3
TIN1: January Indoor Average Temperature Setpoint	C	14,79184
TIN2: February Indoor Average Temperature Setpoint	C	14,81166
TIN3: March Indoor Average Temperature Setpoint	C	15,73763
TIN4: April Indoor Average Temperature Setpoint	C	16,57285
TIN5: May Indoor Average Temperature Setpoint	C	17,64508
TIN6: June Indoor Average Temperature Setpoint	C	18,21178
TIN7: July Indoor Average Temperature Setpoint	C	18,90114
TIN8: August Indoor Average Temperature Setpoint	C	18,81058
TIN9: September Indoor Average Temperature Setpoint	C	17,85461
TIN10: October Indoor Average Temperature Setpoint	C	16,61473
TIN11: November Indoor Average Temperature Setpoir	C	15,60112
TIN12: December Indoor Average Temperature Setpoir	C	15,05366
TINAmp: Daily Indoor sine wave variation amplitude	deltaC	0
ConvTol: Convergence Tolerance		0,1

Figure 57, input parameter: ground heat transfer slab - BldgProps

Field	Units	Obj1
APRatio: The area to perimeter ratio for this slab	m	2,3
SLABDEPTH: Thickness of slab on grade	m	0,3
CLEARANCE: Distance from edge of slab to domain ed	m	15
ZCLEARANCE: Distance from bottom of slab to domain	m	15

Figure 58, input parameter: ground heat transfer slab – EquivalentSlab

Field	Units	Obj1
NMAT: Number of materials in this domain		6
Density for Foundation Wall	kg/m3	514,19
density for Floor Slab	kg/m3	1244,9
density for Ceiling	kg/m3	1244,9
density for Soil	kg/m3	1500
density for Gravel	kg/m3	2000
density for Wood	kg/m3	448,5
Specific heat for foundation wall	J/kg-K	1181
Specific heat for floor slab	J/kg-K	1186,9
Specific heat for ceiling	J/kg-K	1186,9
Specific heat for soil	J/kg-K	840
Specific heat for gravel	J/kg-K	720
Specific heat for wood	J/kg-K	1630
Thermal conductivity for foundation wall	W/m-K	0,1386
Thermal conductivity for floor slab	W/m-K	0,16
Thermal conductivity for ceiling	W/m-K	0,16
thermal conductivity for soil	W/m-K	0,5
thermal conductivity for gravel	W/m-K	1,9
thermal conductivity for wood	W/m-K	0,119

Figure 59, input parameter: basement - MatProps

Field	Units	Obj1
ALBEDO: Surface albedo for No snow conditions		0,16
ALBEDO: Surface albedo for snow conditions		0,4
EPSLN: Surface emissivity No Snow		0,94
EPSLN: Surface emissivity with Snow		0,86
VEGHT: Surface roughness No snow conditions	cm	6
VEGHT: Surface roughness Snow conditions	cm	0,25
PET: Flag, Potential evapotranspiration on?		TRUE

Figure 60, input parameter: basement - SurfaceProps

Field	Units	Obj1
DWALL: Wall thickness	m	0,465
DSLAB: Floor slab thickness	m	0,25
DGRAVXY: Width of gravel pit beside basement wall	m	0,3
DGRAVZN: Gravel depth extending above the floor slal	m	0,2
DGRAVZP: Gravel depth below the floor slab	m	0,1

Figure 61, input parameter: basement - BldgData

Field	Units	Obj1
COND: Flag: Is the basement conditioned?		TRUE
HIN: Downward convection only heat transfer coefficie	W/m2-K	0,92
HIN: Upward convection only heat transfer coefficient	W/m2-K	4,04
HIN: Horizontal convection only heat transfer coefficien	W/m2-K	3,08
HIN: Downward combined (convection and radiation) h	W/m2-K	6,13
HIN: Upward combined (convection and radiation) heat	W/m2-K	9,26
HIN: Horizontal combined (convection and radiation) he	W/m2-K	8,29

Figure 62, input parameter: basement - Interior

Field	Units	Obj1
January average temperature	C	18,35968
February average temperature	C	17,55129
March average temperature	C	17,98188
April average temperature	C	18,71266
May average temperature	C	19,91385
June average temperature	C	22,25723
July average temperature	C	24,23687
August average temperature	C	26,06312
September average temperature	C	23,7424
October average temperature	C	20,89477
November average temperature	C	18,56589
December average temperature	C	17,7385
Daily variation sine wave amplitude	deltaC	0

Figure 63, input parameter: basement - ComBldg

Field	Units	Obj1
CLEARANCE: Distance from outside of wall to edge of :	m	15
SlabDepth: Thickness of the floor slab	m	0,1
BaseDepth: Depth of the basement wall below grade	m	2,4

Figure 64, input parameter: basement – EquivAutoGrid

E. Kostengruppierung der Bauwerkskosten laut ÖNORM 1801-1

	BWK	Bauwerkskosten	
2	BWR	Bauwerk-Rohbau	
	2A	Allgemein	
		2A.01	Besondere Baustelleneinrichtung
		2A.02	Allgemeine Sicherungsmaßnahmen
		2A.03	Sonstiges zu Bauwerk-Rohbau
	2B	Erdarbeiten, Baugrup	
		2B.01	Baugrubenherstellung
		2B.02	Baugrubenumschließung
		2B.03	Wasserhaltung
	2C	Gründungen, Bodenkonstruktionen	
		2C.01	Baugrundverbesserung
		2C.02	Tiefengründungen
		2C.03	Flachgründungen
		2C.04	Bodenkonstruktionen
		2C.05	Bauwerksabdichtungen
	2D	Horizontale Baukonstruktionen	
		2D.01	Deckenkonstruktionen
		2D.02	Treppenkonstruktionen
		2D.03	Dachkonstruktionen
		2D.04	Spezielle Konstruktionen
	2E	Vertikale Baukonstruktionen	
		2E.01	Außenwandkonstruktionen
		2E.02	Innenwandkonstruktionen
		2E.03	Stützenkonstruktionen
		2E.04	Spezielle Konstruktionen
	2G	Rohbau zu Bauwerk-Technik	
		2G.01	Entsorgungsleitungen
		2G.02	Versorgungsleitungen
		2G.03	Rauch- und Abgasfänge

3	BWT	Bauwerk-Technik	
	3A	Allgemein	
		3A.01	Besondere Baustelleneinrichtung
		3A.02	Allgemeine Sicherungsmaßnahme
		3A.03	Sonstiges zu Bauwerk-Technik
	3B	Fördertechnik	
		3B.01	Auszugsanlagen
		3B.02	Fahrtreppen
		3B.03	Befahranlagen
		3B.04	Transportanlagen
		3B.05	Krananlagen
	3C	Wärmeversorgungsanlagen	
		3C.01	Wärmeerzeungsanlagen
		3C.02	Wärmeverteilnetze
		3C.03	Raumheizflächen
	3D	Klima-/Lüftungsanlagen	
		3D.01	Lüftungsanlagen
		3D.02	Teilklimaanlagen
		3D.03	Klimaanlagen
		3D.04	Kälteanlagen
		3D.05	Prozesslufttechnische Anlagen
	3E	Sanitär-/Gasanlagen	
		3E.01	Abwasseranlagen
		3E.02	Wasseranlagen
		3E.03	Gasanlagen
		3E.04	Feuerlöschanlagen
	3F	Starkstromanlagen	
		3F.01	Hoch-/Mittelspannungsanlagen
		3F.02	Eigenstromversorgung
		3F.03	Niederspannungsschaltanlagen
		3F.04	Niederspannungsinstallation
		3F.05	Beleuchtungsanlagen
		3F.06	Blitzschutzanlagen
	3G	Fernmelde- und infomationstechnische Anlagen	
		3G.01	Telekommunikationsanlagen

		3G.02	Such-Signalanlagen
		3G.03	Zeitdienstanlagen
		3G.04	Elektroakustische Anlagen
		3G.05	Fernseh-/Antennenanlagen
		3G.06	Gefahrenmelde-/Alarmanlagen
		3G.07	Übertragungsnetze
	3H	Gebäudeautomation	
		3H.01	Mess-, Steuer, Regel- und Leitanlagen
	3I	Spezielle Anlagen	
		3I.01	Maschinenanlagen
		3I.02	Mechatronische Anlagen

4	BWA	Beuwerk-Ausbau	
	4A	Allgemein	
		4A.01	Besondere Baustelleneinrichtung
		4A.02	Allgemine Sicherungsmaßnahmen
		4A.03	Sonstiges zu Bauwerk-Ausbau
	4B	Dachverkleidung	
		4B.01	Dachbeläge
		4B.02	Dachfenster/-öffnungen
		4B.03	Balkon-/Terrassenbeläge
		4B.04	Feste Einbauteile
	4C	Fassadenhülle	
		4C.01	Fassadenverkleidungen
		4C.02	Fassadenöffnungen
		4C.03	Sonnenschutz
		4C.04	Feste Einbauteile
		4C.05	Außenhülle erdberührt
	4D	Innenausbau	
		4D.01	Bodenbeläge
		4D.02	Wandverkleidungen
		4D.03	Deckenverkleidungen
		4D.04	Innentüren, Innenfenster
		4D.05	Innenwandelemente
		4D.06	Feste Einbauteile
		4D.07	Spezielle Innenausbauteile

F. Meteonorm Data V7.1.1.122

Location name: Unterwart

Latitude [°N]: 47.267 Longitutde [°E]: 16.233

Aktitude [m a.s.l.]: 306 Climate region: III, 3

Radiation model: standard Temperature model: standard

Temperature period: 2000–2009 Radiation period: 1991–2010

Perez: tilt radiation model

Uncertainty of yearly values: Gh = 5 %, Bn = 10 %, Ta = 0.5 °C

Trend of Gh / decade: 2.0 %

Variability of Gh / year: 5.2 %

Radiation interpolation locations: Satellite data

Temperature interpolation locations: KLEINZICKEN (10 km), Szombathely (30 km), SZENTGOTTHARD/FARKA (40 km), SOPRON (54 km), Graz (67 km), WEINER NEUSTADT (63 km)

Month	**G_Gh** [W/m2]	**G_Bn** [W/m2]	**G_Dh** [W/m2]	**Lg** [W/m2]	**Ld** [W/m2]	**N** [octas]	**Ta** [°C]	**Td** [°C]
January	48	68	29	5125	3505	6	-1.3	-4.4
February	80	98	44	8538	5354	5	1.2	-3.1
March	123	117	67	13250	8018	6	5.0	-0.3
April	189	164	92	20356	11236	5	10.6	4.1
May	219	173	113	23897	13873	5	15.5	9.2
June	232	171	120	25515	14741	6	18.6	12.3
July	235	183	117	25853	14553	5	20.2	13.4
August	189	155	98	20925	12237	5	19.6	13.6
September	150	150	73	16577	9321	5	14.6	9.7
October	94	106	49	10378	6263	6	10.1	6.6
November	50	60	32	5539	3962	6	5.0	1.9
December	36	53	23	3922	2806	6	0.0	-2.6
Year	**137**	**125**	**72**	**14990**	**8822**	**6**	**9.9**	**5.0**

Month	RH [%]	p [hPa]	DD [deg]	FF [m/s]
January	79	976	293	1.8
February	73	977	323	2.1
March	68	977	328	2.3
April	64	978	345	2.3
May	66	979	330	2.1
June	67	979	328	1.9
July	65	979	324	2.0
August	68	979	322	1.7
September	72	979	315	1.7
October	79	978	295	1.5
November	80	977	299	1.8
December	82	977	300	1.7
Year	**72**	**978**	**318**	**1.9**

Gh: Mean irradiance of global radiation horizontal

Bn: Irradiance of beam

Dh: Mean irradiance of diffuse radiation horizontal

N: Cloud cover fraction

Lg: Global luminance

Ta: Air temperature

RH: Relative humidity

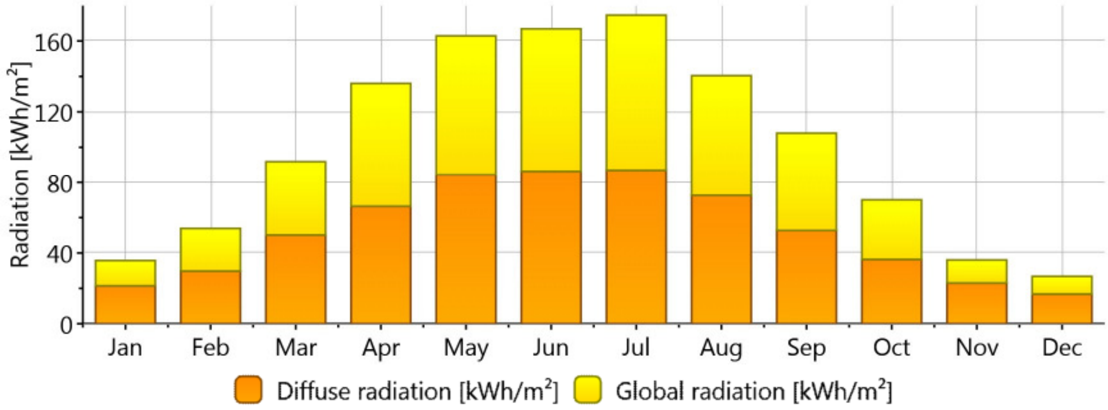
Td: Dewpoint temperature

DD: Wind direction

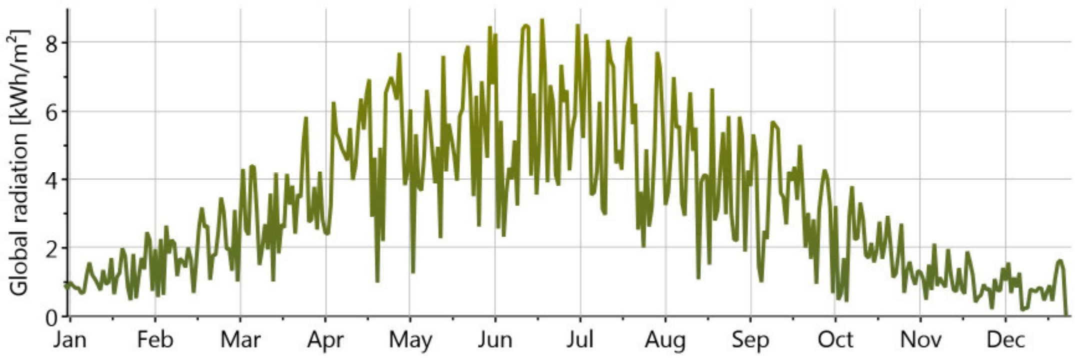
FF: Wind speed

p: Air pressure

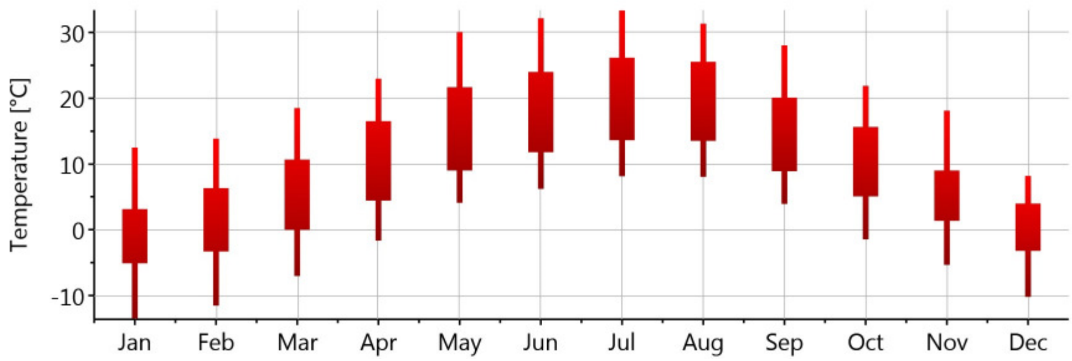
Monthly radiation



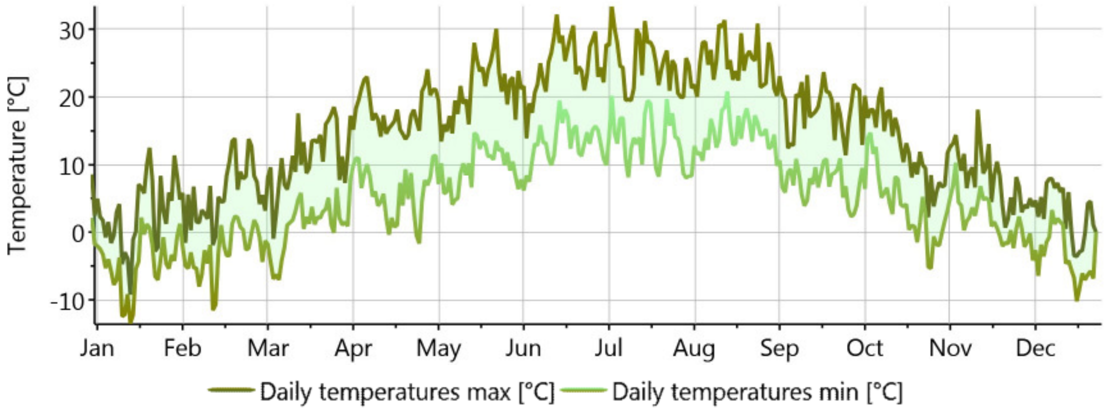
Daily global radiation



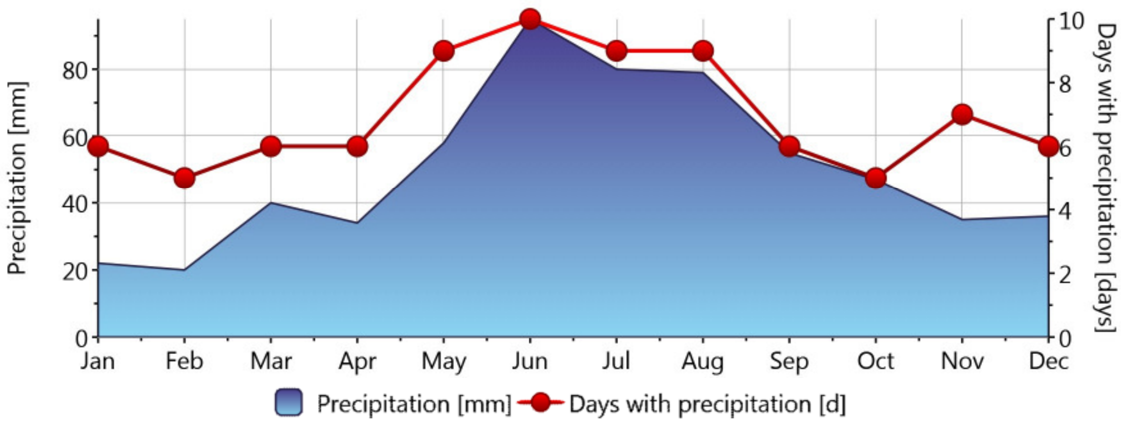
Monthly temperature



Daily temperature



Precipitation



Sunshine duration