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Deliverable 3.3

District evaluation reports from Greece, Austria, Bulgaria and Germany

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OUTPHIT – DEEP RETROFITS MADE FASTER, CHEAPER AND MORE RELIABLE
outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards. **outphit.eu**

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1. INTRODUCTION

As part of the Sinfonia WP4, PHI developed a tool to assess and optimise city districts in terms of energy efficiency. The name of this tool is districtPH. It calculates detailed energy balances for buildings within the neighborhood and allows interaction with these. Heat or electricity production in the district, both centrally and in individual buildings, is considered in the total energy balance. It is possible to account for public supply structures as well as public consumers.

DistrictPH is by far not the only software for such a purpose. Its distinctive features include:

- The tool is fully based on Excel, using a few macros, but not relying on any additional software. The software is not in the public domain, but it is open source, all calculations and algorithms are accessible to the user. This makes it particularly flexible. Users can easily add auxiliary calculations or extensions.
- The structure and the algorithms were chosen such as to allow for quick yet realistic calculations. Monthly energy balances for building types and hourly analysis of supply structures in typical situations allow for a hundred simulations of 50 years' length during the user's lunch break.
- Energy use in buildings is a key aspect. The new tool could build on decades of experience from Passive House research. Well-proven algorithms from the [PHPP] could be used in districtPH, simplified for use on the district level and supplemented for example by specifically developed procedures for estimating the effective indoor temperature in existing, poorly insulated buildings.
- A special focus is on the development of the district over time. The probability of a refurbishment to a certain efficiency level can be defined, depending on factors like component age, time, or existing efficiency level.

The development was aiming at two major fields of interest:

- The energy balance of the district, including heat and electricity generators and grids, at a given point in time. Questions such as 'What is required to make the district zero-energy?', 'What would be an appropriate size for a seasonal heat storage?', 'How much energy will be exported from the district in a specific situation?' can be addressed.
- The interaction of current and future retrofits with supply structures. Possible projections include the total primary energy demand or the CO2 emissions over several decades, depending on different scenarios for e.g. retrofit subsidies or district heating network installations.

For the outPHit project DistrictPH shows is a tool that aims to promote energy efficiency in buildings by examining different districts and developing transferable solutions for improving energy efficiency. In order to achieve this goal, the project team selected various districts from different countries and scaled them to create a basis for comparing energy efficiency considerations.

One of the key examples used in the project was Germany, where the entire country was considered as a district and analyzed using the district PH approach.

A general summary of the results can be found under General Conclusion at the end. Here, the results and statements of the individual studies, related to the countries, are worked through again.

The attached appendix provides detailed explanations of the basic structure of the district PH, as well as the building models used to make assumptions for the calculations. It also outlines the various methods that were found to be useful and those that were deemed unsuitable for such calculations. Additionally, the appendix includes information on aspects such as thermal comfort and variations, which are important considerations when analyzing energy efficiency in buildings.

Overall, the outPHit project seeks to develop transferable solutions that can be applied to different districts and countries to improve energy efficiency in buildings. By analyzing and comparing different approaches and techniques, the project aims to provide valuable insights into how energy efficiency can be achieved on a larger scale.

2. GREECE

2.1. EXISTING SITUATION

Figure 1: The neighborhood in Athens.

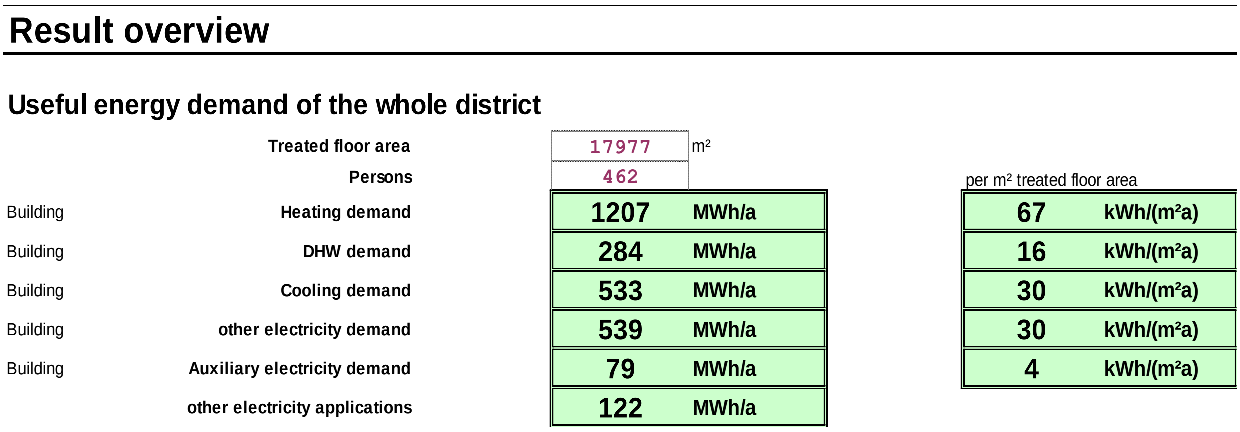
This neighborhood contains 14 buildings, which were constructed before 1980 without any insulation and 4 buildings with 3cm of insulation.

The simulation was performed for the whole neighbourhood taking into consideration all the parameters mentioned in Part A. The district consists of 17.977m^2 TFA and about 462 users:

- Heating Demand = 67kWh/m^{2}a
- DHW Demand = 16kWh/m^{2}a
- Cooling Demand = 30kWh/m^{2}a
- Electricity Demand = 30kWh/m^{2}a
- Other electricity Demand = 4kWh/m^{2}a

Key Information: The total heating demand was calculated using the Monte Carlo simulation and the indoor temperature is assumed to be 17,1 °C. The same assumption was made also for the cooling demand while the indoor temperature for the cooling period is 28,1 °C.

The total Primary Energy Demand (PE) for the whole district is 147kWh/m^{2}a. Detailed information can be seen in the following figure (5).



Result overview

Useful energy demand of the whole district

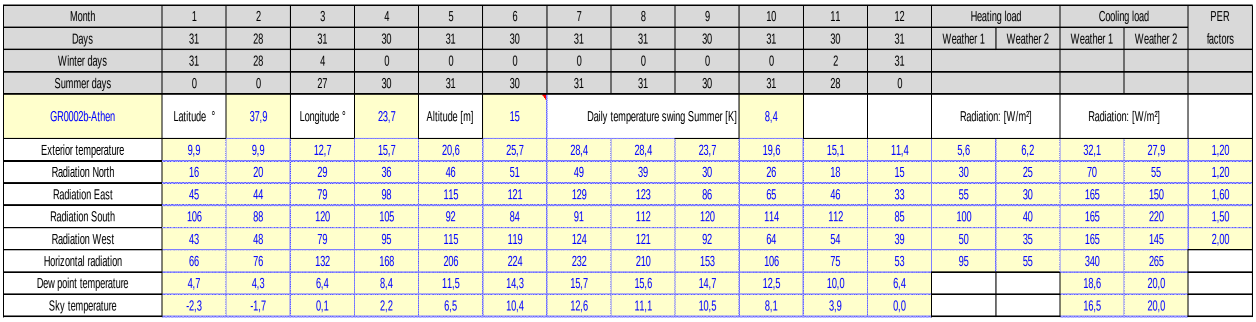
	Treated floor area	17977	m²		
	Persons	462		per m² treated floor area	
Building	Heating demand	1207	MWh/a	67	kWh/(m²a)
Building	DHW demand	284	MWh/a	16	kWh/(m²a)
Building	Cooling demand	533	MWh/a	30	kWh/(m²a)
Building	other electricity demand	539	MWh/a	30	kWh/(m²a)
Building	Auxiliary electricity demand	79	MWh/a	4	kWh/(m²a)
	other electricity applications	122	MWh/a		

Figure 2: Overview results of the existing situation.

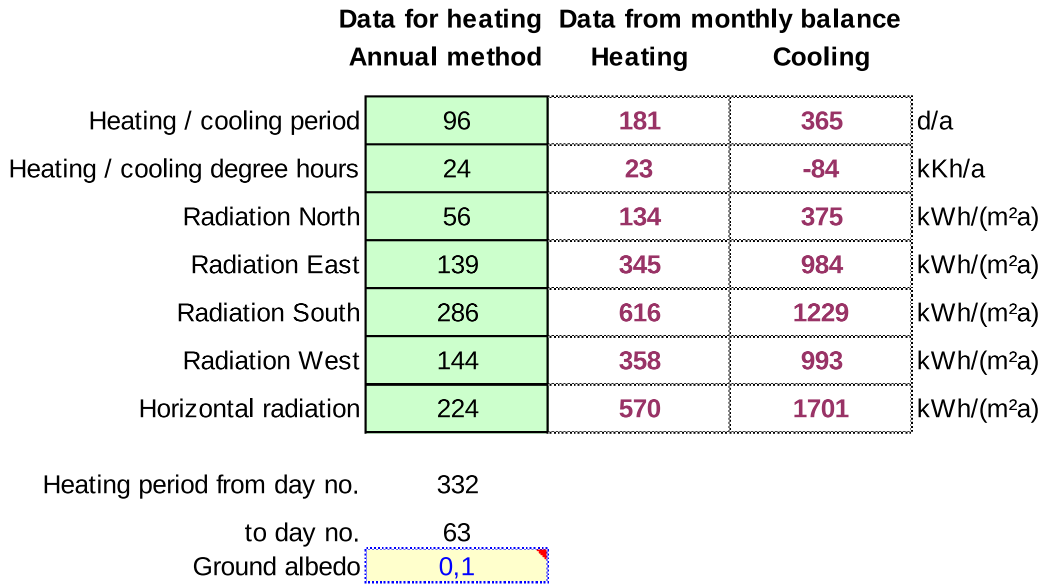
2.1.1. CLIMATE DATA SET

The used climate data set for Athens was obtained through simulation and a combination of different sources like: Meteonorm, Hellenic National Meteorological Service, NASA and was validated from Passive House Institute GmbH.

Further details of the climate data set can be observed in the figures below.



Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating load		Cooling load		PER
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Weather 1	Weather 2	factors
Winter days	31	28	4	0	0	0	0	0	0	0	2	31					
Summer days	0	0	27	30	31	30	31	31	30	31	28	0					
GR0002b-Athen	Latitude °	37,9	Longitude °	23,7	Altitude [m]	15	Daily temperature swing Summer [K]			8,4			Radiation: [W/m²]		Radiation: [W/m²]		
Exterior temperature	9,9	9,9	12,7	15,7	20,6	25,7	28,4	28,4	23,7	19,6	15,1	11,4	5,6	6,2	32,1	27,9	1,20
Radiation North	16	20	29	36	46	51	49	39	30	26	18	15	30	25	70	55	1,20
Radiation East	45	44	79	98	115	121	129	123	86	65	46	33	55	30	165	150	1,60
Radiation South	106	88	120	105	92	84	91	112	120	114	112	85	100	40	165	220	1,50
Radiation West	43	48	79	95	115	119	124	121	92	64	54	39	50	35	165	145	2,00
Horizontal radiation	66	76	132	168	206	224	232	210	153	106	75	53	95	55	340	265	
Dew point temperature	4,7	4,3	6,4	8,4	11,5	14,3	15,7	15,6	14,7	12,5	10,0	6,4			18,6	20,0	
Sky temperature	-2,3	-1,7	0,1	2,2	6,5	10,4	12,6	11,1	10,5	8,1	3,9	0,0			16,5	20,0	

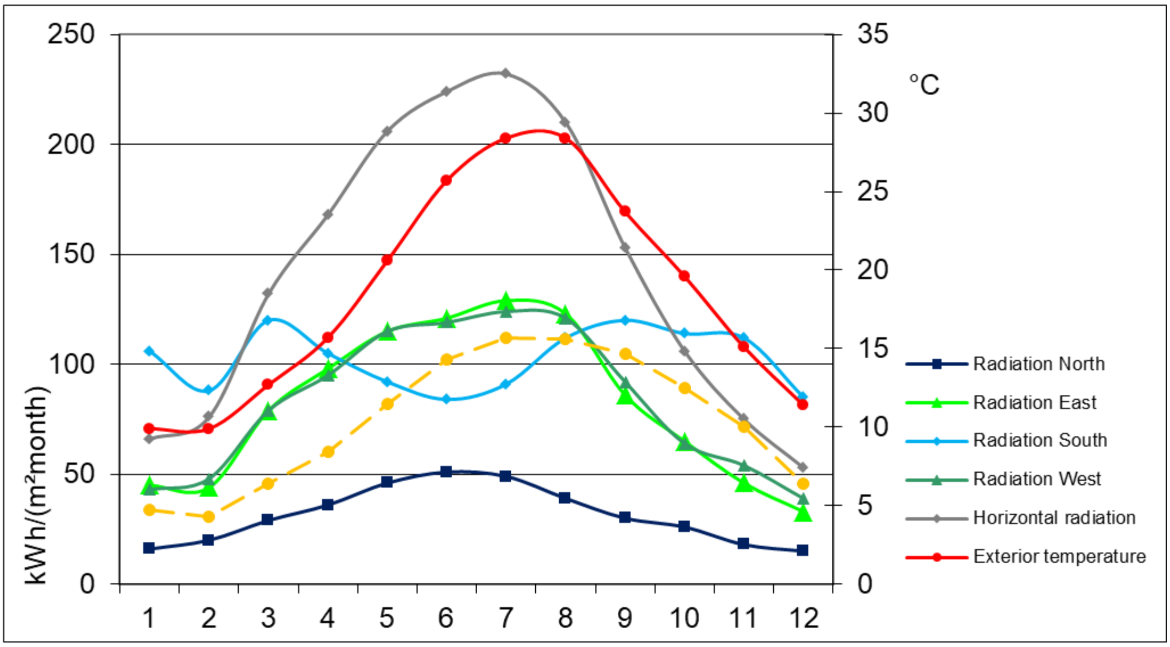


	Data for heating Annual method	Data from monthly balance Heating	 Cooling	
Heating / cooling period	96	181	365	d/a
Heating / cooling degree hours	24	23	-84	kKh/a
Radiation North	56	134	375	kWh/(m²a)
Radiation East	139	345	984	kWh/(m²a)
Radiation South	286	616	1229	kWh/(m²a)
Radiation West	144	358	993	kWh/(m²a)
Horizontal radiation	224	570	1701	kWh/(m²a)

Heating period from day no. 332

to day no. 63

Ground albedo 0,1



2.1.2. TYPOLOGY

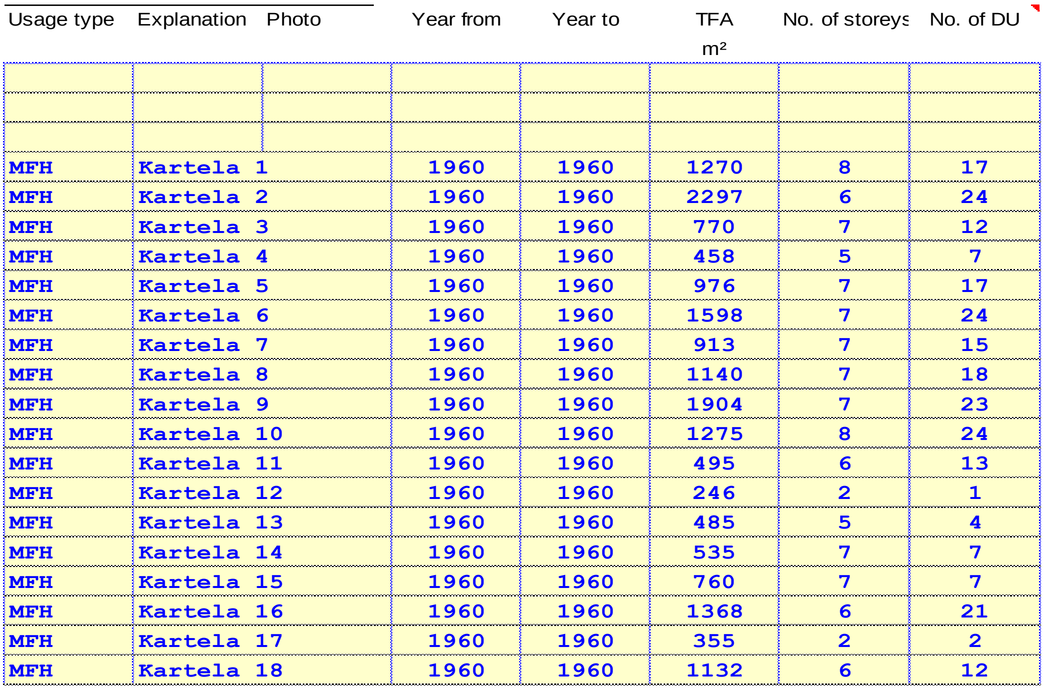
Detailed information regarding the geometry and the orientation of the whole district was entered into the districtPH software. This is defined in the chapter 3.1:

- Total Treated Floor Area = 17.977m^2
- Total No. of storeys = 110
- No. of dwelling units = 248
- Roof Area = 3.927m^2

- Wall Area = 14.047m^2
- Floor Area = 3.867m^2
- Door Area = 72m^2
- East Windows Area = 633m^2
- South Windows Area = 955,5m^2
- West Windows Area = 536,4m^2
- North Windows Area = 976,1m^2

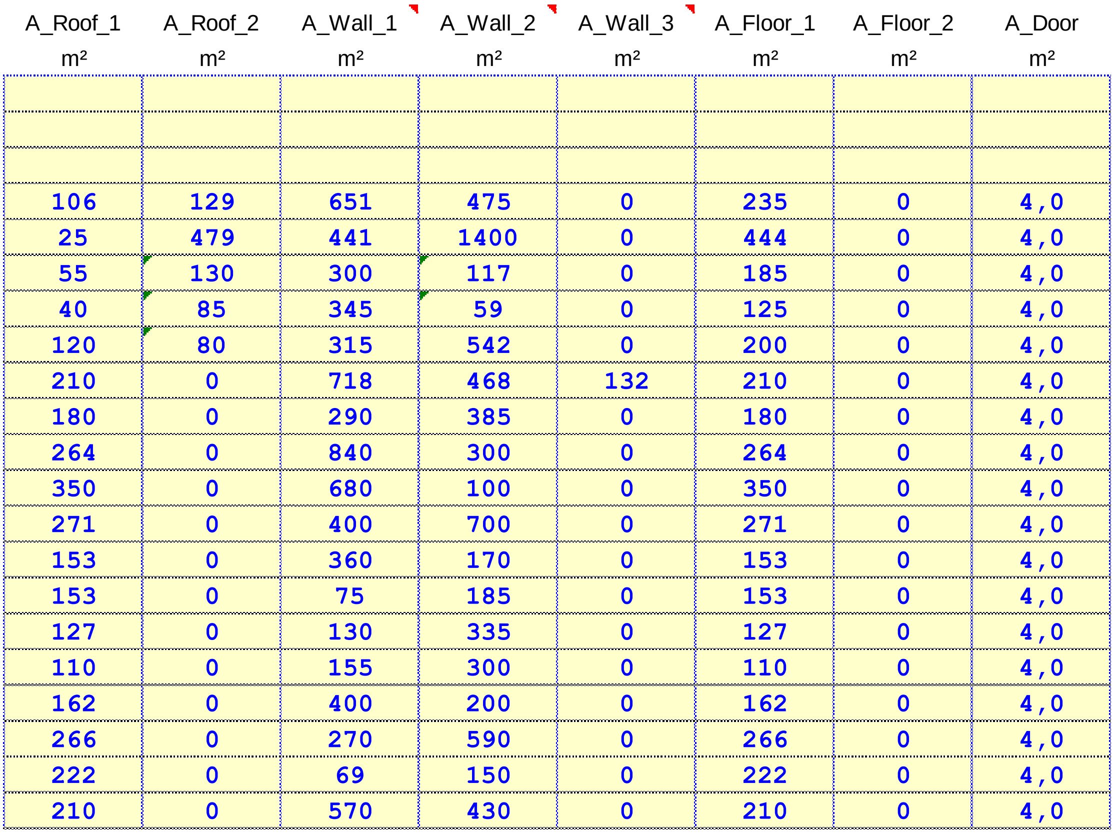
All areas are in contact with outdoor air except the floor area which is in contact with an unheated basement. There are two different types of building assemblies for the roof and three different types for the wall. For terraced buildings, the shared side walls weren't taken into consideration concerning the heating losses.

Detailed input information can be noticed in the next three figures.



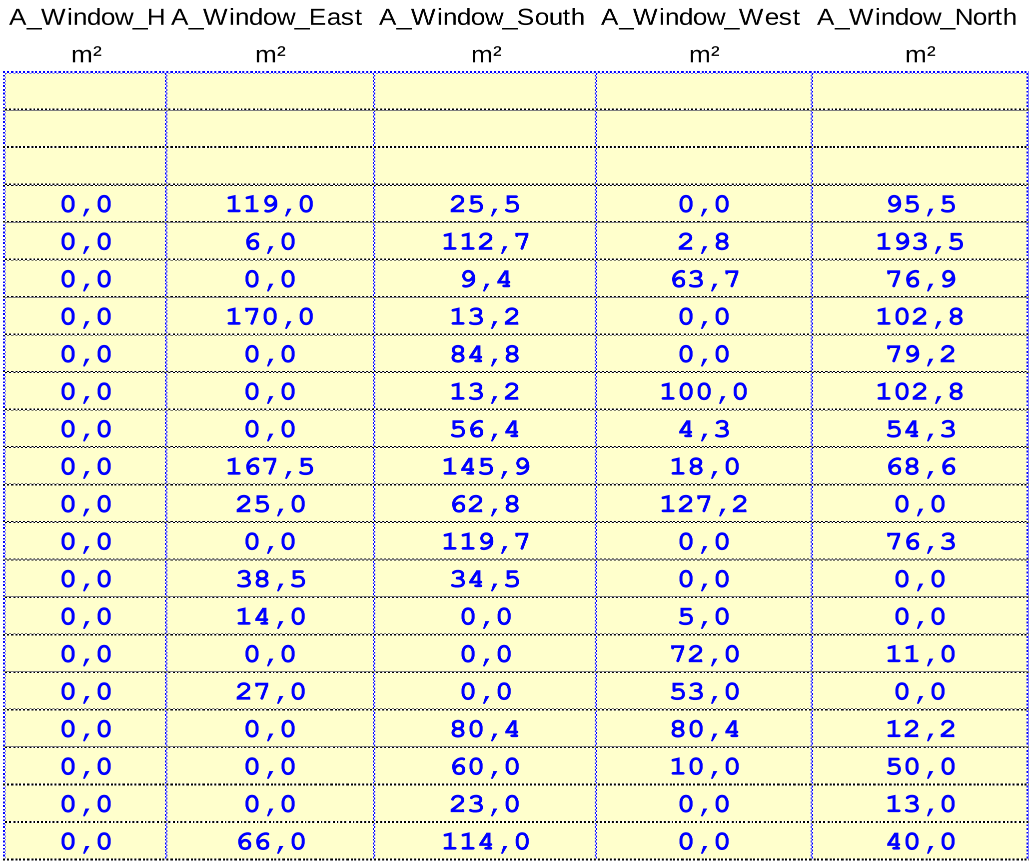
Usage type	Explanation	Photo	Year from	Year to	TFA m²	No. of storeys	No. of DU
MFH	Kartela 1		1960	1960	1270	8	17
MFH	Kartela 2		1960	1960	2297	6	24
MFH	Kartela 3		1960	1960	770	7	12
MFH	Kartela 4		1960	1960	458	5	7
MFH	Kartela 5		1960	1960	976	7	17
MFH	Kartela 6		1960	1960	1598	7	24
MFH	Kartela 7		1960	1960	913	7	15
MFH	Kartela 8		1960	1960	1140	7	18
MFH	Kartela 9		1960	1960	1904	7	23
MFH	Kartela 10		1960	1960	1275	8	24
MFH	Kartela 11		1960	1960	495	6	13
MFH	Kartela 12		1960	1960	246	2	1
MFH	Kartela 13		1960	1960	485	5	4
MFH	Kartela 14		1960	1960	535	7	7
MFH	Kartela 15		1960	1960	760	7	7
MFH	Kartela 16		1960	1960	1368	6	21
MFH	Kartela 17		1960	1960	355	2	2
MFH	Kartela 18		1960	1960	1132	6	12

Figure 3: Typology worksheet 1.



A_Roof_1 m²	A_Roof_2 m²	A_Wall_1 m²	A_Wall_2 m²	A_Wall_3 m²	A_Floor_1 m²	A_Floor_2 m²	A_Door m²
106	129	651	475	0	235	0	4,0
25	479	441	1400	0	444	0	4,0
55	130	300	117	0	185	0	4,0
40	85	345	59	0	125	0	4,0
120	80	315	542	0	200	0	4,0
210	0	718	468	132	210	0	4,0
180	0	290	385	0	180	0	4,0
264	0	840	300	0	264	0	4,0
350	0	680	100	0	350	0	4,0
271	0	400	700	0	271	0	4,0
153	0	360	170	0	153	0	4,0
153	0	75	185	0	153	0	4,0
127	0	130	335	0	127	0	4,0
110	0	155	300	0	110	0	4,0
162	0	400	200	0	162	0	4,0
266	0	270	590	0	266	0	4,0
222	0	69	150	0	222	0	4,0
210	0	570	430	0	210	0	4,0

Figure 4: Typology worksheet 2.



A_Window_H m²	A_Window_East m²	A_Window_South m²	A_Window_West m²	A_Window_North m²
0,0	119,0	25,5	0,0	95,5
0,0	6,0	112,7	2,8	193,5
0,0	0,0	9,4	63,7	76,9
0,0	170,0	13,2	0,0	102,8
0,0	0,0	84,8	0,0	79,2
0,0	0,0	13,2	100,0	102,8
0,0	0,0	56,4	4,3	54,3
0,0	167,5	145,9	18,0	68,6
0,0	25,0	62,8	127,2	0,0
0,0	0,0	119,7	0,0	76,3
0,0	38,5	34,5	0,0	0,0
0,0	14,0	0,0	5,0	0,0
0,0	0,0	0,0	72,0	11,0
0,0	27,0	0,0	53,0	0,0
0,0	0,0	80,4	80,4	12,2
0,0	0,0	60,0	10,0	50,0
0,0	0,0	23,0	0,0	13,0
0,0	66,0	114,0	0,0	40,0

Figure 5: Typology worksheet 3.

2.1.3. BUILDING ELEMENTS

The thermal envelope of the existing buildings is totally uninsulated for the majority of the district's buildings. That means that the U-Values for the wall, the floor, the roof and the windows are the following:

- U-Wall = 3,4W/m^{2}K
- U-Floor = 3,1W/m^{2}K
- U-Roof = 3,05W/m^{2}K
- U-Door = 4W/m^{2}K
- U-Window = 4,7W/m^{2}K
- g-Window = 0,58

The heat losses through the envelope are crucial and even in a city like Athens, with high average temperatures, the heating demand is high.

2.1.4. THERMAL BRIDGES

There are two types of thermal bridges: 1. Geometric and 2. Structural

Geometric TB, are caused by geometrical disconnection of a building element (ex. a corner). Constructional TB, are caused by material discontinuity of a building element (ex. a balcony).

Concerning this total uninsulated building, both types of thermal bridges occur. For example a concrete slab ($\lambda=2{,}3W/m^2K$) penetrating a brick wall ($\lambda=0{,}64W/m^2K$). Calculating the most important thermal bridges of each building, an average result of $0{,}15W/m^2K$ heat losses due to thermal bridges was calculated.

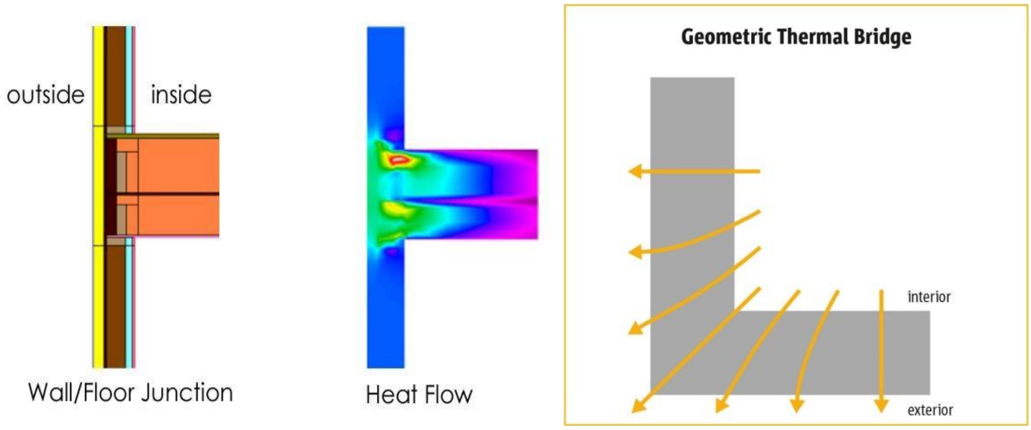


Figure 6: Left hand side Constructional TB, right hand side Geometric TB.

The thermal bridges in totally uninsulated buildings do not have a significant impact on a building's heat losses, because the heat flux remains fairly uniform in the case of uninsulated buildings. The heat losses through every surface of the building are high, so the psi-value of the correction between two building elements is not so high.

Linear Ψ-value is calculated using external dimensions through the following formula:

$$\Psi = \frac{Q_{2Dim} - Q_{1Dim}}{\Delta\theta}$$

Detailed,

$Q_{1Dim} = \Sigma\, Ai \cdot Ui \cdot \Delta\theta\, i$

Q_{2Dim}: Heat flux 2-Dimensions, calculated through dynamic simulation

$\Delta\theta$: Temperature difference between indoor and outdoor air

U_i: U-value of building elements "i"

A_i: Building element, area number "i", (external dimensions)

$\Delta\theta_i$: Temperature difference between the surface temperature of building element "i".

DistrictPH calculates the heat losses of the thermal bridges according to the following formula:

$$\mathbf{Q_T = l \cdot \Psi \cdot f_T \cdot G_t}$$

Detailed,

l: Length of thermal bridge

Ψ: Linear thermal transmission coefficient

f_T: Temperature factor

G_t: Time integer of temperature difference (Heating Degree hours)

2.1.5. AIRTIGHTNESS

The air leakages through the envelope in old and uninsulated buildings are significant and constitute a portion of the total heat losses that cannot be neglected. It is not feasible to conduct a pressurization test on each building, however the input values were taken from case studies in conventional buildings in Italy. The building system of the aforementioned buildings consists of concrete-brick assemblies, similar to the typical constructions in Greece, where the n50 value is from 5 to 8 air changes per hour [Lannetti 2018]. In this particular study, the n50 value is assumed to have an average value of **6 ach^{-1}** for each building.

2.1.6. HEATING/ COOLING CARRIER – DHW – ELECTRICITY

Based on data available, the heating and cooling demand is covered by electrical heating coils individually in the apartments and it can be safely assumed that in some apartments it is not covered at all, meaning that the some operate in free floating conditions. For the domestic hot water demand, a similar assumption can be made since no solar thermal systems are installed in the buildings. As far as the other electric devices are concerned, an efficiency level 5 was selected for their performance, which means that, on average, these devices were installed between 2000 and 2010.

2.1.7. HEATING PERIOD

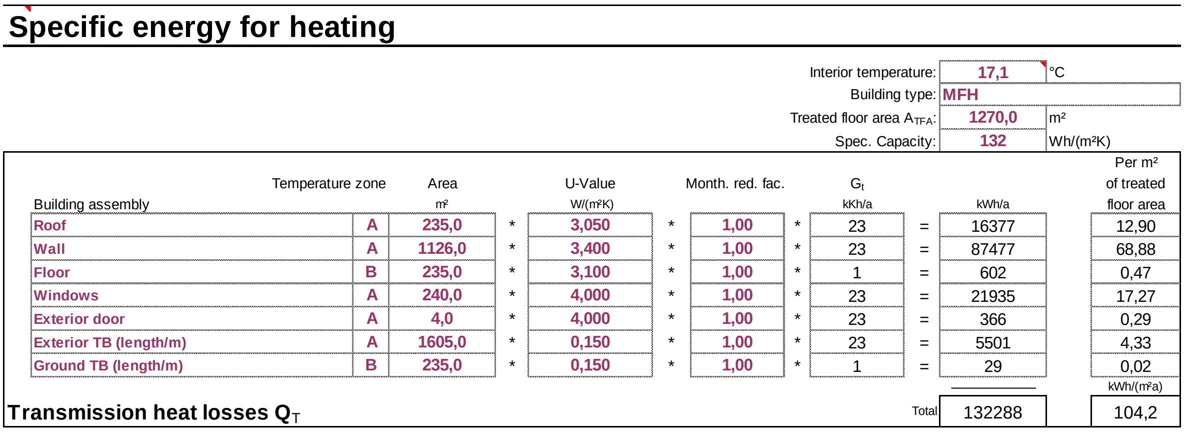
The detailed energy demand for one of these buildings is calculated according to EN ISO 13790 with same formulas as in Passive House Planning Package (PHPP).

The U values of the different building assemblies are represented in figure 10. The transmission heat losses **Q_T** through the building envelope are calculated to be **104,2kWh/m^{2}a**

The ventilation heat losses **Q_v** due to infiltration and the lack of a good airtightness level, which account for **10kWh/m^{2}a,** are presented in figure 11. The overall heat losses **Q_L** are **114,2kWh/m^{2}a**.

The solar heat gains **Q_S (34,8kWh/m^{2}a),** the internal heat gains **Q_I (12kWh/m^{2}a)** and the total heat gains **Q_G (39,8kWh/m^{2}a)** are demonstrated in figure 12.

Based on the energy balance of the building, the annual heating demand of this particular building results to be equal to **Q_H (74kWh/m^{2}a)**.

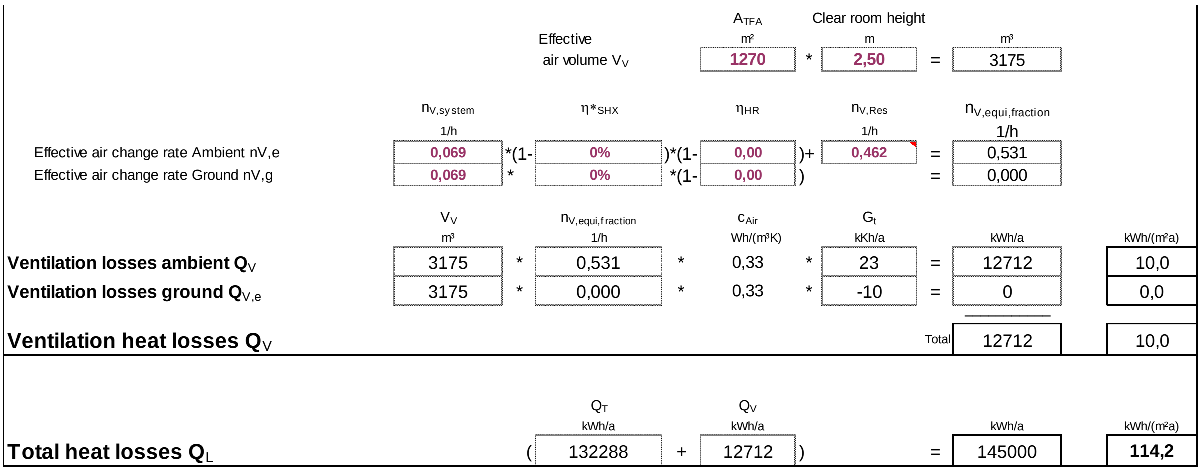


Specific energy for heating

Interior temperature:	17,1	°C
Building type:	MFH	
Treated floor area A_{TFA}:	1270,0	m²
Spec. Capacity:	132	Wh/(m²K)

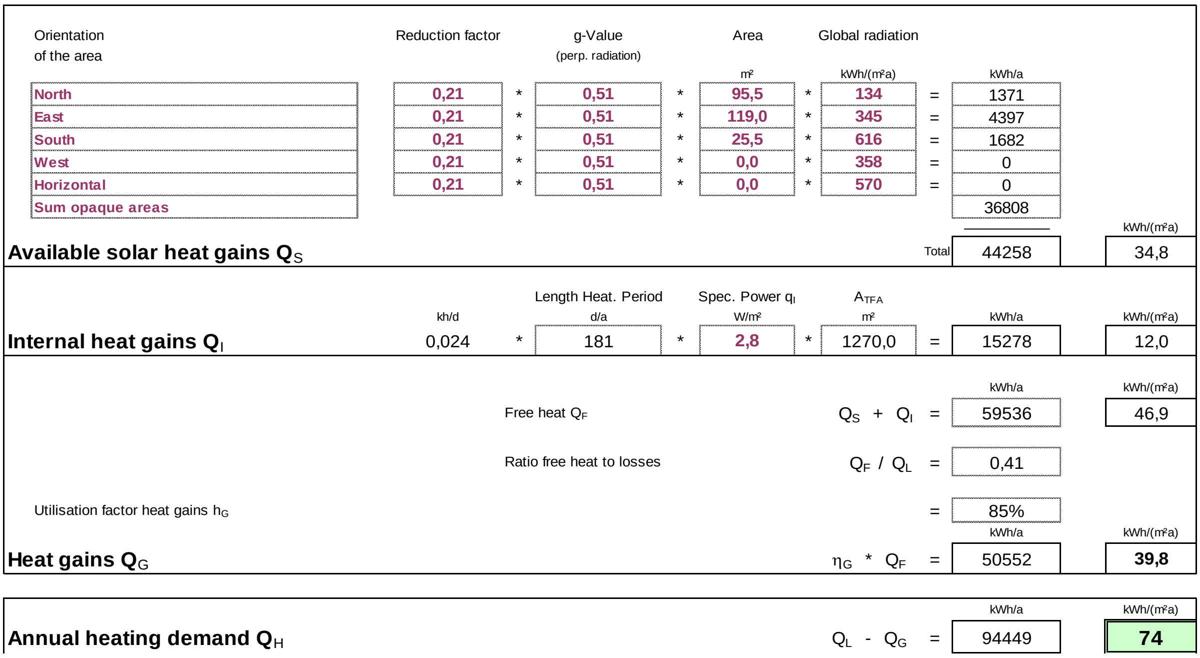
Building assembly	Temperature zone	Area m²		U-Value W/(m²K)		Month. red. fac.		G_t kKh/a		kWh/a	Per m² of treated floor area
Roof	A	235,0	*	3,050	*	1,00	*	23	=	16377	12,90
Wall	A	1126,0	*	3,400	*	1,00	*	23	=	87477	68,88
Floor	B	235,0	*	3,100	*	1,00	*	1	=	602	0,47
Windows	A	240,0	*	4,000	*	1,00	*	23	=	21935	17,27
Exterior door	A	4,0	*	4,000	*	1,00	*	23	=	366	0,29
Exterior TB (length/m)	A	1605,0	*	0,150	*	1,00	*	23	=	5501	4,33
Ground TB (length/m)	B	235,0	*	0,150	*	1,00	*	1	=	29	0,02
											kWh/(m²a)
Transmission heat losses Q_T									Total	132288	104,2

Figure 7: Transmission heat losses.



			Effective air volume V_V		A_{TFA} m²		Clear room height m		m³	
					1270	*	2,50	=	3175	
	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h	
Effective air change rate Ambient nV,e	0,069	*(1-	0%	)*(1-	0,00	)+	0,462	=	0,531	
Effective air change rate Ground nV,g	0,069	*	0%	*(1-	0,00	)		=	0,000	
	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation losses ambient Q_V	3175	*	0,531	*	0,33	*	23	=	12712	10,0
Ventilation losses ground $Q_{V,e}$	3175	*	0,000	*	0,33	*	-10	=	0	0,0
Ventilation heat losses Q_V								Total	12712	10,0
			Q_T kWh/a		Q_V kWh/a				kWh/a	kWh/(m²a)
Total heat losses Q_L		(	132288	+	12712	)		=	145000	**114,2**

Figure 8: Ventilation heat losses – total heat losses.



Orientation of the area	Reduction factor		g-Value (perp. radiation)		Area m²		Global radiation kWh/(m²a)		kWh/a	
North	0,21	*	0,51	*	95,5	*	134	=	1371	
East	0,21	*	0,51	*	119,0	*	345	=	4397	
South	0,21	*	0,51	*	25,5	*	616	=	1682	
West	0,21	*	0,51	*	0,0	*	358	=	0	
Horizontal	0,21	*	0,51	*	0,0	*	570	=	0	
Sum opaque areas									36808	
										kWh/(m²a)
Available solar heat gains Q_S								Total	44258	34,8
	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal heat gains Q_I	0,024	*	181	*	2,8	*	1270,0	=	15278	12,0
									kWh/a	kWh/(m²a)
			Free heat Q_F				Q_S + Q_I	=	59536	46,9
			Ratio free heat to losses				Q_F / Q_L	=	0,41	
Utilisation factor heat gains h_G								=	85%	
									kWh/a	kWh/(m²a)
Heat gains Q_G							η_G * Q_F	=	50552	**39,8**
									kWh/a	kWh/(m²a)
Annual heating demand Q_H							Q_L - Q_G	=	94449	**74**

Figure 9: Heat gains – annual heating demand.

The monthly specific heating demand is calculated by taking into account the different factors of the building (building assemblies, geometry, orientation etc) and the climate data of Athens. The results are shown in figure 13.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating degree hours - Externa	5,8	5,2	3,8	1,6	-1,9	-5,4	-7,5	-7,5	-4,1	-1,3	1,9	4,7	-5	kKh
Heating degree hours - Ground	0,3	0,4	0,4	0,1	-6,3	-6,5	-7,1	-7,2	-6,9	-6,8	-0,4	0,0	-40	kKh
Losses - Exterior	36520	33129	23808	9803	-12122	-33963	-47219	-47182	-25782	-8196	11708	29399	-30095	kWh
Losses - Ground	257	328	293	65	-4807	-4973	-5391	-5497	-5252	-5201	-317	5	-30488	kWh
Sum spec. losses	29,0	26,3	19,0	7,8	-13,3	-30,7	-41,4	-41,5	-24,4	-10,5	9,0	23,2	-47,7	kWh/m²
Solar gains - North	164	205	297	368	470	522	501	399	307	266	184	153	3836	kWh
Solar gains - East	574	561	1007	1249	1466	1542	1644	1568	1096	828	586	421	12541	kWh
Solar gains - South	289	240	328	287	251	229	249	306	328	311	306	232	3356	kWh
Solar gains - West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar gains - Opaque	4854	4997	8106	9512	11074	11685	12168	11571	9001	6828	5394	3946	99135	kWh
Internal heat gains	2617	2363	2617	2532	2617	2532	2617	2617	2532	2617	2532	2617	30809	kWh
Sum spec. gains solar + intern	6,7	6,6	9,7	11,0	12,5	13,0	13,5	13,0	10,4	8,5	7,1	5,8	117,9	kWh/m²
Utilisation factor	98%	98%	91%	59%	100%	100%	100%	100%	100%	100%	81%	98%	-104%	
Annual heating demand	28414	25250	12865	1604	0	0	0	0	0	0	4140	22176	94449	kWh
Spec. heating demand	**22,4**	**19,9**	**10,1**	**1,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**3,3**	**17,5**	**74,4**	kWh/m²

Figure 10: Monthly specific heating demand.

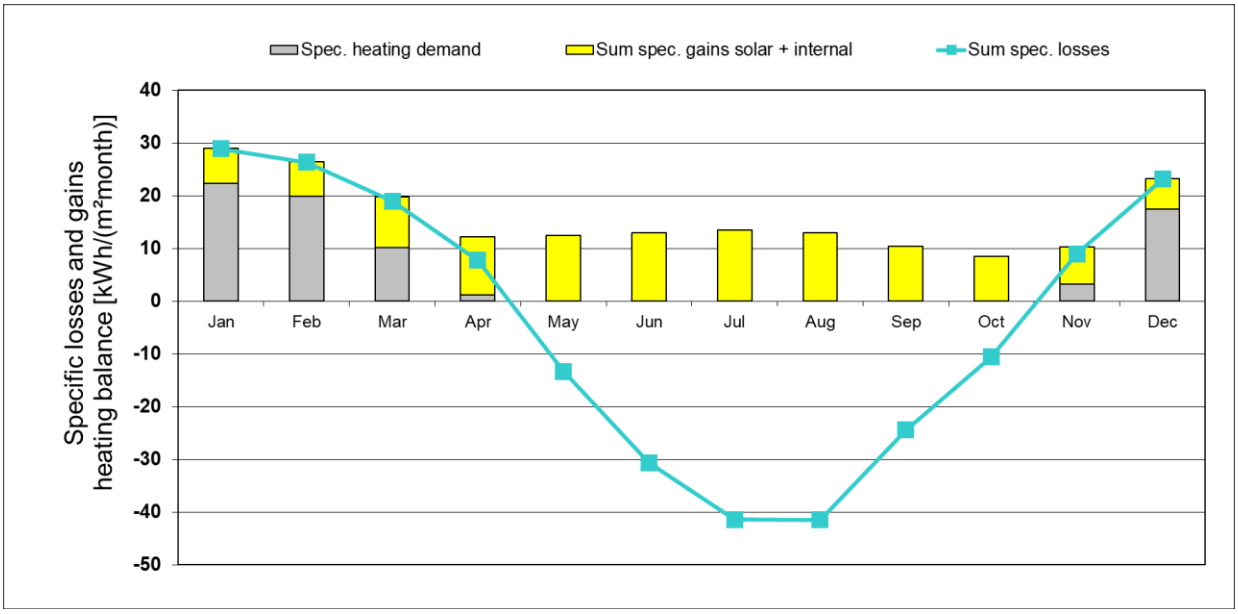


Figure 11: Monthly heating balance.

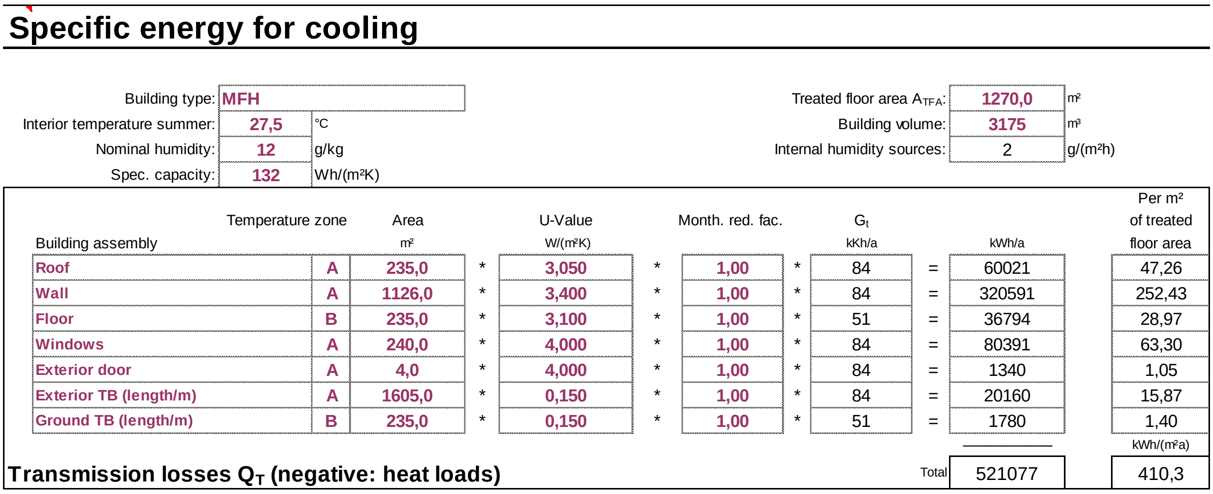
2.1.8. COOLING PERIOD

The same procedure described for the heating period was followed for the case of the cooling period for the same building of the neighbourhood.

The transmission losses **Q_T** are **410,3kWh/m²a**, the ventilation heat losses **Q_V** are **51,8kWh/m²a** and the total heat losses equal to **Q_L** are **462,1kWh/m²a (**figure 15 and 16 correspondingly**).**

The available solar heat gains **Q_S** are **82,7kWh/m²a,** the internal heat gains **Q_I** are **24,3 kWh/m²a** and the total Heat Loads **Q_F** are **107 kWh/m²a** (figure 17).

The results are the Useful heat losses **$Q_{V,n}$ (78kWh/m²a)** and the useful cooling demand **Q_K (29kWh/m²a)** (figure 18)

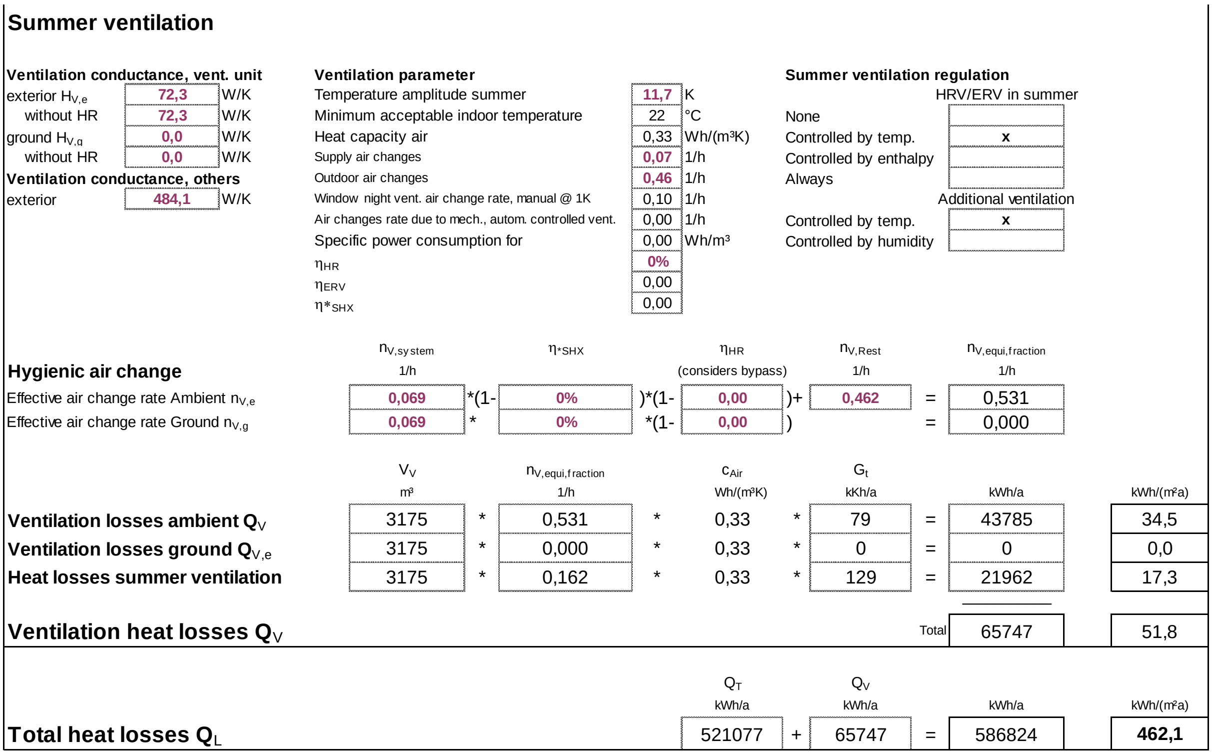


Specific energy for cooling

Building type:	MFH		Treated floor area A_{TFA}:	1270,0	m²
Interior temperature summer:	27,5	°C	Building volume:	3175	m³
Nominal humidity:	12	g/kg	Internal humidity sources:	2	g/(m²h)
Spec. capacity:	132	Wh/(m²K)			

Building assembly	Temperature zone	Area m²		U-Value W/(m²K)		Month. red. fac.		G_t kKh/a		kWh/a	Per m² of treated floor area
Roof	A	235,0	*	3,050	*	1,00	*	84	=	60021	47,26
Wall	A	1126,0	*	3,400	*	1,00	*	84	=	320591	252,43
Floor	B	235,0	*	3,100	*	1,00	*	51	=	36794	28,97
Windows	A	240,0	*	4,000	*	1,00	*	84	=	80391	63,30
Exterior door	A	4,0	*	4,000	*	1,00	*	84	=	1340	1,05
Exterior TB (length/m)	A	1605,0	*	0,150	*	1,00	*	84	=	20160	15,87
Ground TB (length/m)	B	235,0	*	0,150	*	1,00	*	51	=	1780	1,40
											kWh/(m²a)
Transmission losses Q_T (negative: heat loads)									Total	521077	410,3

Figure 12: Transmission heat losses.



Summer ventilation

Ventilation conductance, vent. unit		
exterior $H_{V,e}$	72,3	W/K
without HR	72,3	W/K
ground $H_{V,g}$	0,0	W/K
without HR	0,0	W/K
Ventilation conductance, others		
exterior	484,1	W/K

Ventilation parameter		
Temperature amplitude summer	11,7	K
Minimum acceptable indoor temperature	22	°C
Heat capacity air	0,33	Wh/(m³K)
Supply air changes	0,07	1/h
Outdoor air changes	0,46	1/h
Window night vent. air change rate, manual @ 1K	0,10	1/h
Air changes rate due to mech., autom. controlled vent.	0,00	1/h
Specific power consumption for	0,00	Wh/m³
η_{HR}	0%	
η_{ERV}	0,00	
η^*_{SHX}	0,00	

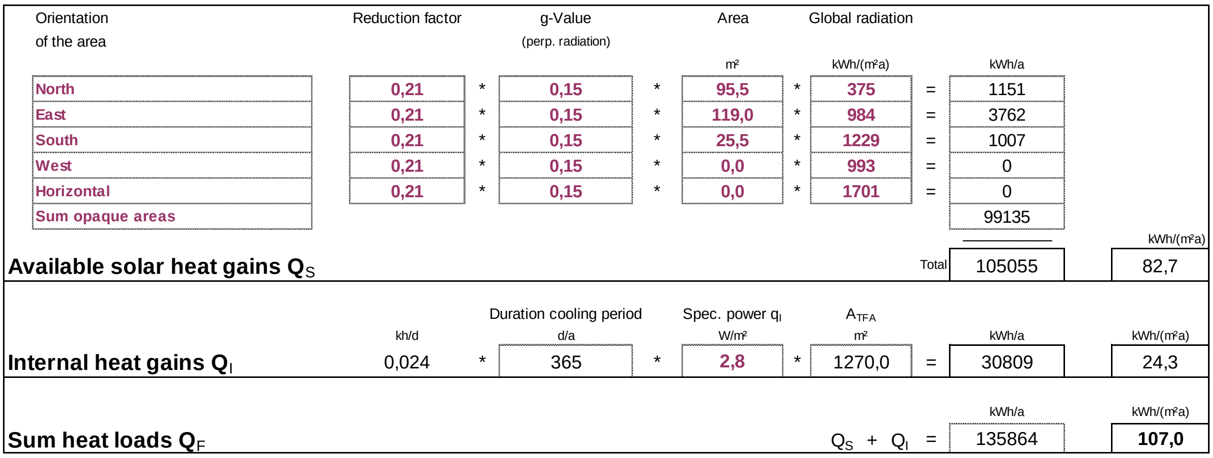
Summer ventilation regulation	HRV/ERV in summer
None	
Controlled by temp.	x
Controlled by enthalpy	
Always	
	Additional ventilation
Controlled by temp.	x
Controlled by humidity	

Hygienic air change	$n_{V,system}$ 1/h		η_{*SHX}		η_{HR} (considers bypass)		$n_{V,Rest}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective air change rate Ambient $n_{V,e}$	0,069	*(1-	0%	)*(1-	0,00	)+	0,462	=	0,531
Effective air change rate Ground $n_{V,g}$	0,069	*	0%	*(1-	0,00	)		=	0,000

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation losses ambient Q_V	3175	*	0,531	*	0,33	*	79	=	43785	34,5
Ventilation losses ground $Q_{V,e}$	3175	*	0,000	*	0,33	*	0	=	0	0,0
Heat losses summer ventilation	3175	*	0,162	*	0,33	*	129	=	21962	17,3
Ventilation heat losses Q_V								Total	65747	51,8

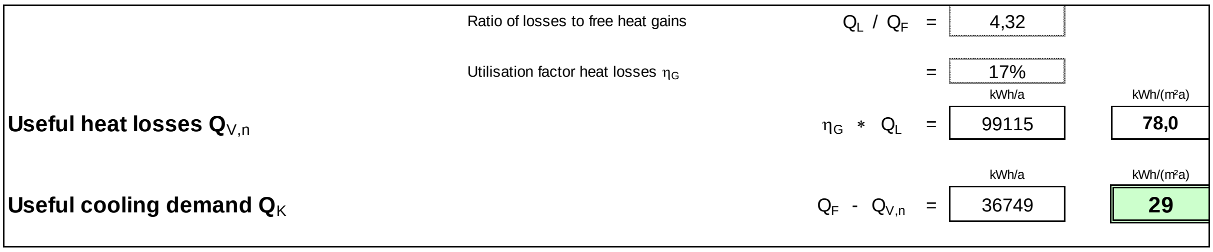
	Q_T kWh/a		Q_V kWh/a		kWh/a	kWh/(m²a)
Total heat losses Q_L	521077	+	65747	=	586824	**462,1**

Figure 13: Ventilation heat losses – total heat losses.



Orientation of the area	Reduction factor		g-Value (perp. radiation)		Area		Global radiation			
					m²		kWh/(m²a)		kWh/a	
North	0,21	*	0,15	*	95,5	*	375	=	1151	
East	0,21	*	0,15	*	119,0	*	984	=	3762	
South	0,21	*	0,15	*	25,5	*	1229	=	1007	
West	0,21	*	0,15	*	0,0	*	993	=	0	
Horizontal	0,21	*	0,15	*	0,0	*	1701	=	0	
Sum opaque areas									99135	
										kWh/(m²a)
Available solar heat gains Q_S								Total	105055	82,7
			Duration cooling period		Spec. power q_I		A_{TFA}			
	kh/d		d/a		W/m²		m²		kWh/a	kWh/(m²a)
Internal heat gains Q_I	0,024	*	365	*	2,8	*	1270,0	=	30809	24,3
									kWh/a	kWh/(m²a)
Sum heat loads Q_F							Q_S + Q_I	=	135864	**107,0**

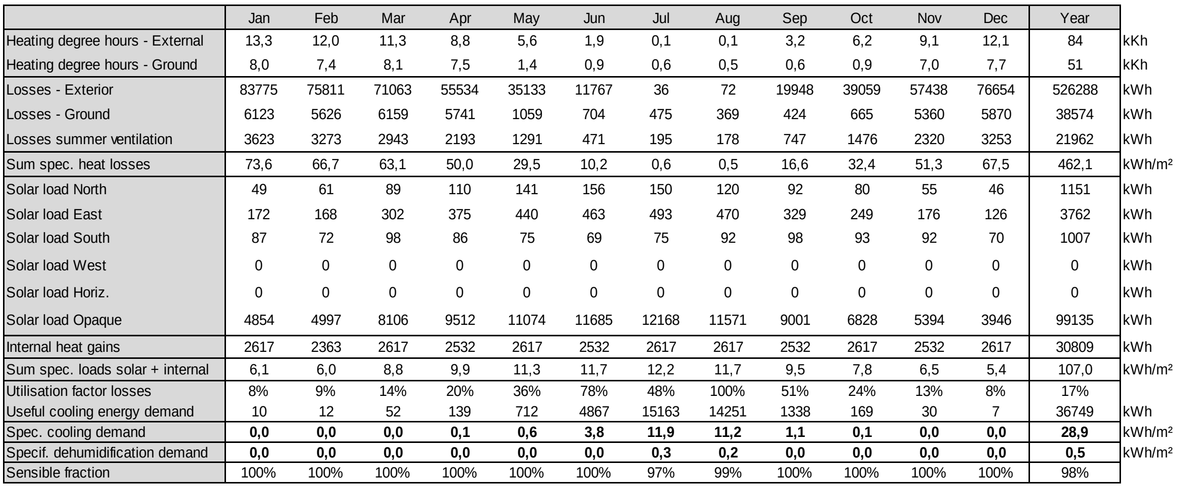
Figure 14: Heat gains – heat loads.



Ratio of losses to free heat gains	Q_L / Q_F	=	4,32	
Utilisation factor heat losses η_G		=	17%	
			kWh/a	kWh/(m²a)
Useful heat losses $Q_{V,n}$	η_G * Q_L	=	99115	**78,0**
			kWh/a	kWh/(m²a)
Useful cooling demand Q_K	Q_F - $Q_{V,n}$	=	36749	**29**

Figure 15: Useful heat losses – useful cooling demand.

Monthly calculations made by taking into consideration different factors, are presented in the next figure (19).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating degree hours - External	13,3	12,0	11,3	8,8	5,6	1,9	0,1	0,1	3,2	6,2	9,1	12,1	84	kKh
Heating degree hours - Ground	8,0	7,4	8,1	7,5	1,4	0,9	0,6	0,5	0,6	0,9	7,0	7,7	51	kKh
Losses - Exterior	83775	75811	71063	55534	35133	11767	36	72	19948	39059	57438	76654	526288	kWh
Losses - Ground	6123	5626	6159	5741	1059	704	475	369	424	665	5360	5870	38574	kWh
Losses summer ventilation	3623	3273	2943	2193	1291	471	195	178	747	1476	2320	3253	21962	kWh
Sum spec. heat losses	73,6	66,7	63,1	50,0	29,5	10,2	0,6	0,5	16,6	32,4	51,3	67,5	462,1	kWh/m²
Solar load North	49	61	89	110	141	156	150	120	92	80	55	46	1151	kWh
Solar load East	172	168	302	375	440	463	493	470	329	249	176	126	3762	kWh
Solar load South	87	72	98	86	75	69	75	92	98	93	92	70	1007	kWh
Solar load West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar load Opaque	4854	4997	8106	9512	11074	11685	12168	11571	9001	6828	5394	3946	99135	kWh
Internal heat gains	2617	2363	2617	2532	2617	2532	2617	2617	2532	2617	2532	2617	30809	kWh
Sum spec. loads solar + internal	6,1	6,0	8,8	9,9	11,3	11,7	12,2	11,7	9,5	7,8	6,5	5,4	107,0	kWh/m²
Utilisation factor losses	8%	9%	14%	20%	36%	78%	48%	100%	51%	24%	13%	8%	17%	
Useful cooling energy demand	10	12	52	139	712	4867	15163	14251	1338	169	30	7	36749	kWh
Spec. cooling demand	**0,0**	**0,0**	**0,0**	**0,1**	**0,6**	**3,8**	**11,9**	**11,2**	**1,1**	**0,1**	**0,0**	**0,0**	**28,9**	kWh/m²
Specif. dehumidification demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,3**	**0,2**	**0,0**	**0,0**	**0,0**	**0,0**	**0,5**	kWh/m²
Sensible fraction	100%	100%	100%	100%	100%	100%	97%	99%	100%	100%	100%	100%	98%	

Figure 16: Monthly calculations.

The cooling period has a duration of five months and lasts from May to September according to the graph above (figure 20).

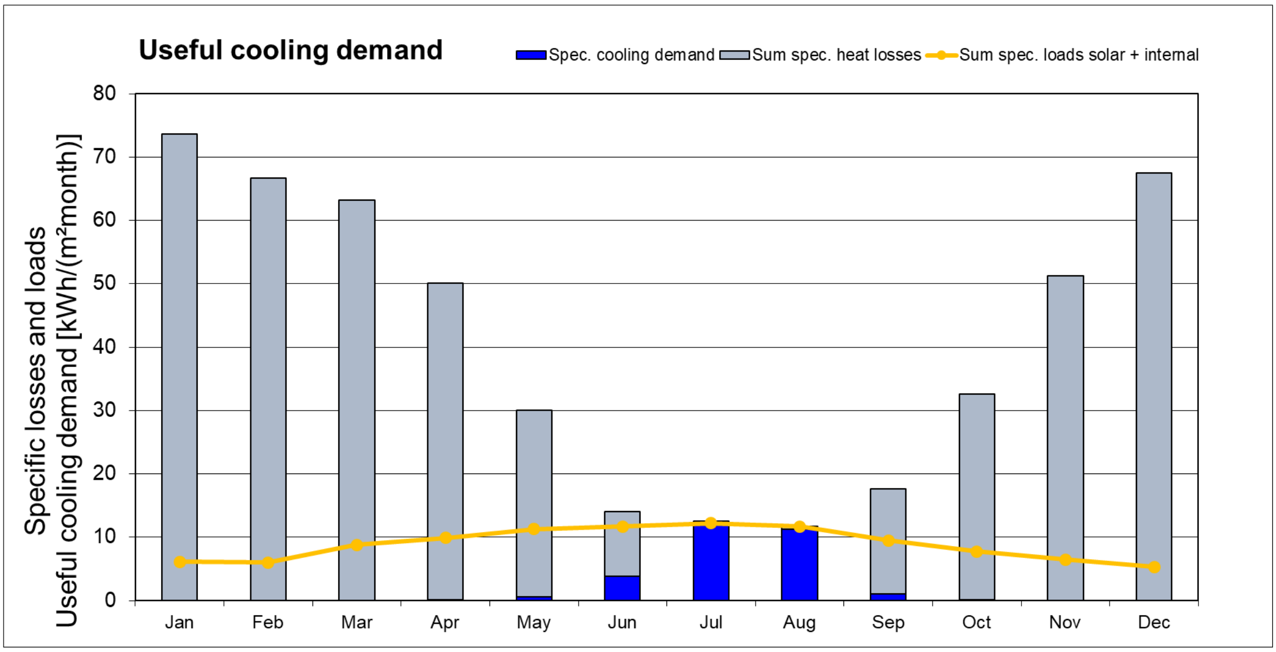


Figure 17: Useful cooling demand.

2.2. REFURBISHED DISTRICT

The whole district will be refurbished in **one step** following a holistic approach. The study will be implemented according to the Passive House concept.

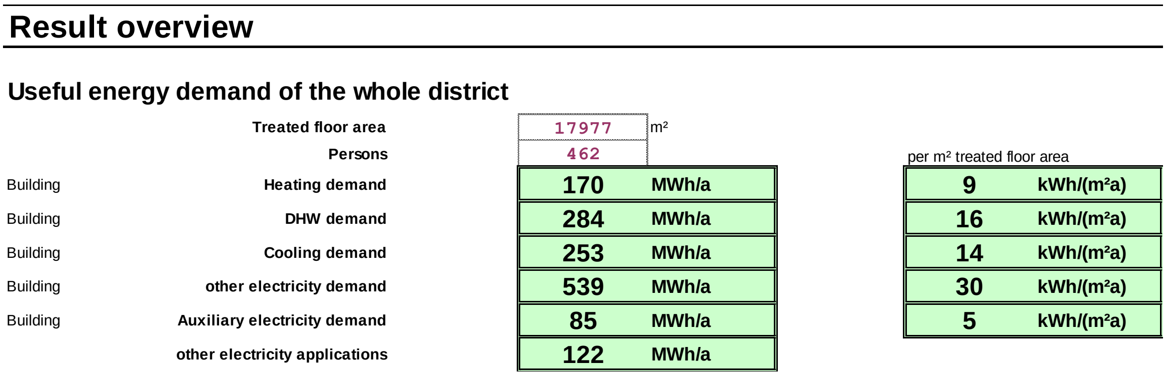
The simulation was carried out for the whole neighbourhood taking into consideration all the parameters mentioned in Part A. The results of the energy demand of the district after the refurbishment is as follows:

- Heating Demand = 9kWh/m^{2}a
- DHW Demand = 16kWh/m^{2}a
- Cooling Demand = 14kWh/m^{2}a
- Electricity Demand = 30kWh/m^{2}a
- Other electricity Demand = 5kWh/m^{2}a

Key Information: The total heating demand was calculated using the Monte Carlo simulation and the indoor temperature is assumed to be **20 ℃**. The same assumption was made also for the cooling demand while the indoor temperature for the cooling period is **25 ℃**.

These conditions (20 to 25 °C) along with the relative humidity which should be between the margins of 35-55% and the CO_2 concentration in ppm (below 1000). These three conditions determine the perfect indoor condition and is a requirement for a Passive House.

The total Primary Energy Demand (PE) for the whole district is 74kWh/m^{2}a. Detailed information can be seen in the following figure (21).



Result overview

Useful energy demand of the whole district

	Treated floor area	17977	m²		
	Persons	462		per m² treated floor area	
Building	Heating demand	170	MWh/a	9	kWh/(m²a)
Building	DHW demand	284	MWh/a	16	kWh/(m²a)
Building	Cooling demand	253	MWh/a	14	kWh/(m²a)
Building	other electricity demand	539	MWh/a	30	kWh/(m²a)
Building	Auxiliary electricity demand	85	MWh/a	5	kWh/(m²a)
	other electricity applications	122	MWh/a		

Figure 18: Result overview – refurbished district.

2.2.1. PASSIVE HOUSE CONCEPT

The Passive House concept was invented from Dr. Prof. Wolfgang Feist and Dr. Bo Adamson in 1988. The main goal was to achieve the best possible energy efficiency and the best indoor conditions for the users.

It is based on five principles which are:

- Well insulated thermal envelope
- High-Performance windows
- Airtight construction
- Thermal Bridge free construction
- Mechanical Ventilation with Heat Recovery

The biggest advantage of this concept, in comparison to others, is that everything is measurable and the targets are well defined from the beginning until the end. Many scientists believe that, the Passive House is the world leading standard in energy-efficient constructions: A Passive House requires as little as 10 percent of the energy consumed by typical European buildings – meaning energy savings of up to 90 percent. Owners of Passive Houses are barely concerned with increasing energy prices. **To achieve a Passive House**:

- Passive Houses require less than **15 kWh/(m²yr)** for heating or cooling.
- The heating/cooling load is limited to a maximum of **10 W/m².**
- Conventional Primary energy use may not exceed 120 kWh/(m²a) - but the newest approach requires buildings to operate fully using renewable energy supply (PER) with no more than 60 kWh/(m²a). This is easy to accomplish with passive houses.
- Passive Houses must be airtight with air change rates being limited to **n50 = 0.6/h**.
- In warmer climates and/or during summer months**, excessive temperatures** may not occur more than **10 %** of the time in case no active cooling is used.

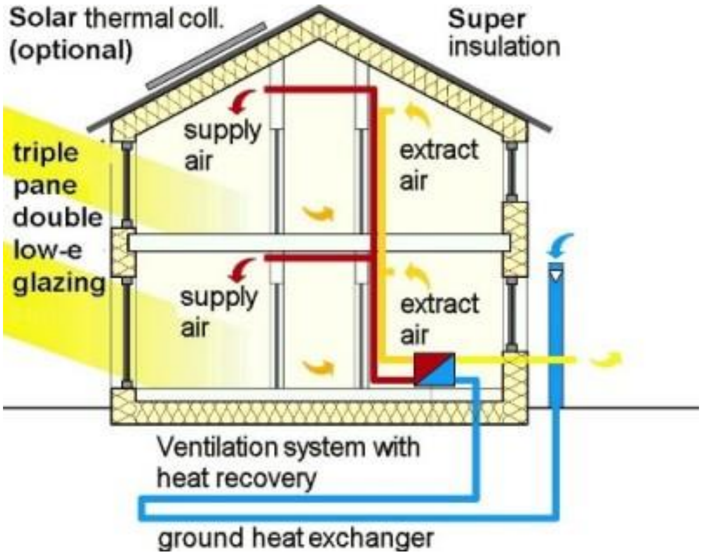


Figure 19: The 5 principles of a passive house. [Passipedia]

2.2.2. BUILDING ELEMENTS

Climate Data Set –and Typology are identical to the ones described in chapter 7.1.1. and 7.1.2.

Regarding the refurbished district, following the Passive House concept, the best possible result was achieved without the requirement of U-values below 0,200 or 0,150W/m^{2}K as it is typical in central Europe. This is possible to be realized due to three main reasons:

- The ratio A/V (Area, Volume) is low in Multifamily Houses and it is a significant factor to achieve energy efficiency
- Most of the buildings are terraced and therefore the heat losses from the walls are halved due to the presence of intermediate walls of buildings in the same district.
- The climate and the heat island effect in Athens lead to mild winters.

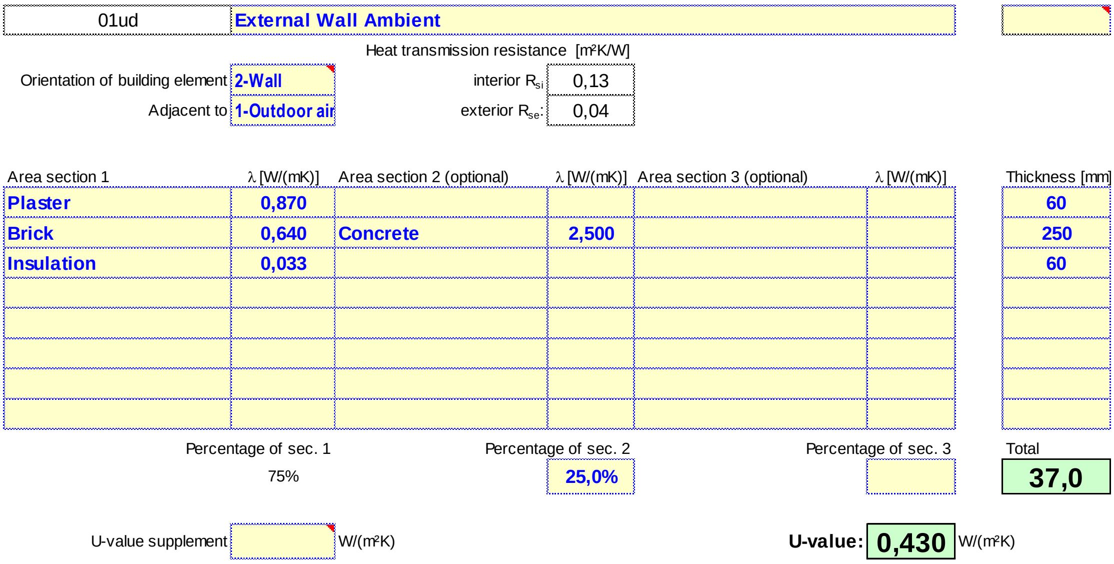
The thermal envelope of the existing buildings is now fully insulated. That means that the U-Values for the wall, the floor, the roof and the windows are the following:

- U-Wall = 0,430W/m^{2}K
- U-Floor = 0,5W/m^{2}K
- U-Roof = 0,384W/m^{2}K
- U-Door = 0,8W/m^{2}K
- U-Window = 1,1W/m^{2}K
- g-Window = 0,50

The heat losses through the envelope are crucial and following these improvements for the thermal envelope, energy savings of up to 86,6% were achieving the whole district.

In details:

- **Walls:** The external walls of the building which are in contact with the outdoor air will be covered with 6cm external insulation with thermal conductivity equal to λ=0.033W/mK



01ud **External Wall Ambient**

Heat transmission resistance [m²K/W]

Orientation of building element **2-Wall** interior R_{si} 0,13

Adjacent to **1-Outdoor air** exterior R_{se}: 0,04

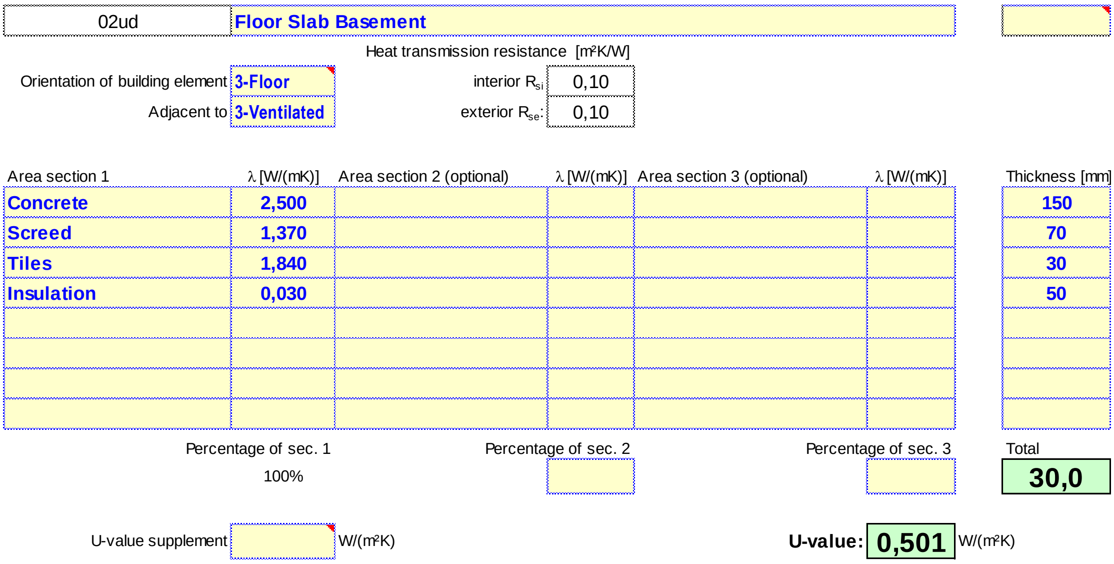
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Plaster	**0,870**					**60**
Brick	**0,640**	**Concrete**	**2,500**			**250**
Insulation	**0,033**					**60**

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
75%	**25,0%**		**37,0**

U-value supplement W/(m²K)

U-value: **0,430** W/(m²K)

- **Floor slab**: All 18 buildings have a basement which is not considered to be part of the thermal envelope. The basement ceiling will be insulated with 5cm insulation with thermal conductivity equal to λ=0.030W/mK



02ud **Floor Slab Basement**

Heat transmission resistance [m²K/W]

Orientation of building element **3-Floor** interior R_{si} 0,10

Adjacent to **3-Ventilated** exterior R_{se}: 0,10

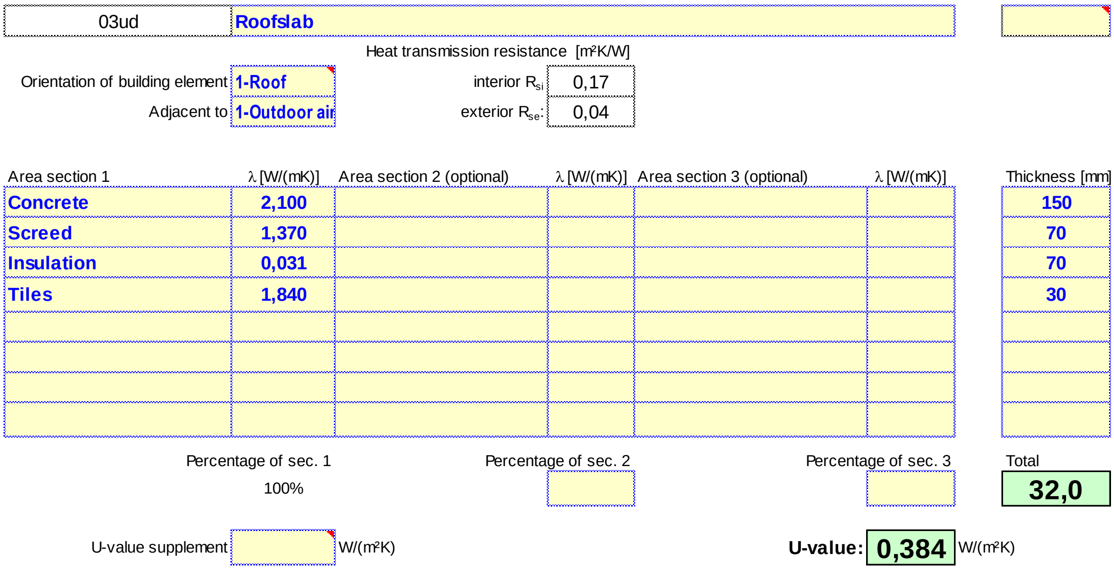
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	**2,500**					**150**
Screed	**1,370**					**70**
Tiles	**1,840**					**30**
Insulation	**0,030**					**50**

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			**30,0**

U-value supplement W/(m²K)

U-value: **0,501** W/(m²K)

- **Roof slab:** 7cm of insulation will be installed externally in every roof.



03ud	Roofslab

Heat transmission resistance [m²K/W]

Orientation of building element: 1-Roof — interior R_{si}: 0,17

Adjacent to: 1-Outdoor air — exterior R_{se}: 0,04

Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	2,100					150
Screed	1,370					70
Insulation	0,031					70
Tiles	1,840					30

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			32,0

U-value supplement W/(m²K)

U-value: 0,384 W/(m²K)

- **Windows:** The thermal characteristics of the windows are as follows:
  - Frame with U_{frame} = 1,25W/m^{2}K
  - Double glazing with g-value = 0,5 and U_g = 1,1W/m^{2}K.

  Total U-value of the window, **U_{window} = 1,1W/m^{2}K**

2.2.3. THERMAL BRIDGES

Existing buildings contain a huge amount of thermal bridges. It is impossible to achieve a thermal bridge free construction but it is possible to minimize the biggest amount of these details. For this particular study, the thermal bridge details were calculated using the software: **HTFlux** and **Flixo Pro.**

Two main indicative details for the 18 buildings will be presented:

- **Balcony:** A fully uninsulated balcony is one of the energy consuming thermal bridges in a building with insulated walls and a potential mould and condensation source. In the next figures, the materials (23), the temperature (24) and the heat flux (25) can be observed.

  As it can be seen, the influence of the thermal bridge is Ψ = 0,875 W/mK, which would result in a substantial increase of the energy demand of the building. The internal surface temperature is 14°C. Based on the internal and external conditions (T_i=20 °C - RH_i=80% T_e=-10 °C - RH_e=80% respectively) the critical temperature for mould formation is 12,6°C. The internal surface temperature is slightly higher, however there is still a risk of mould formation.

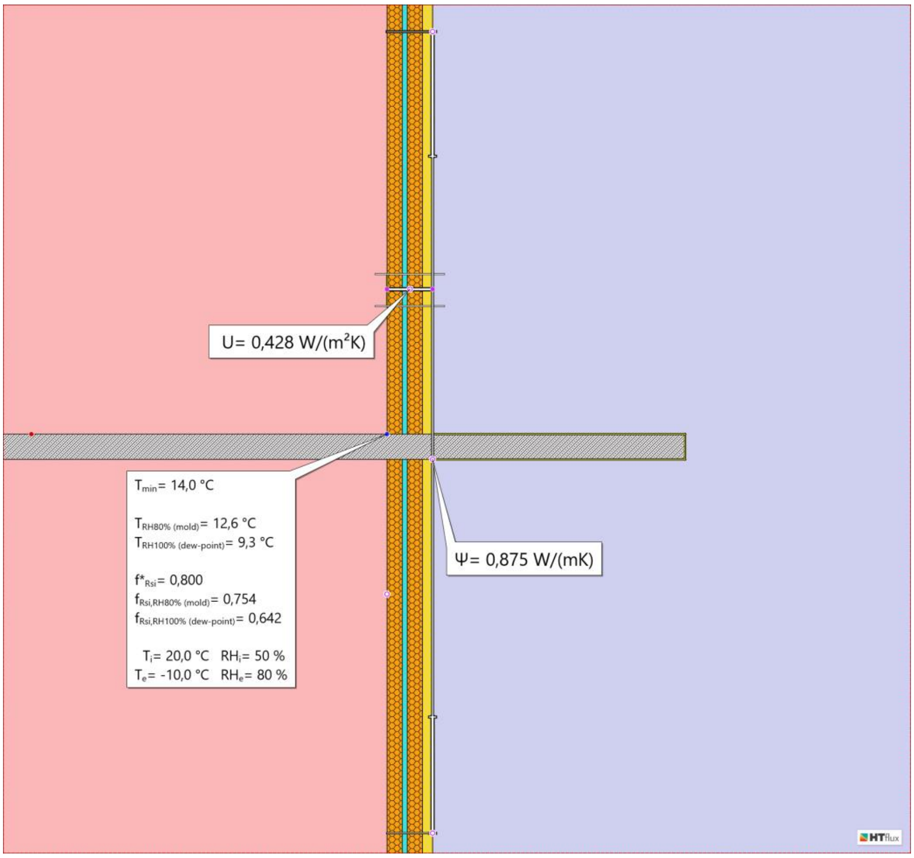


Figure 20: Materials used.

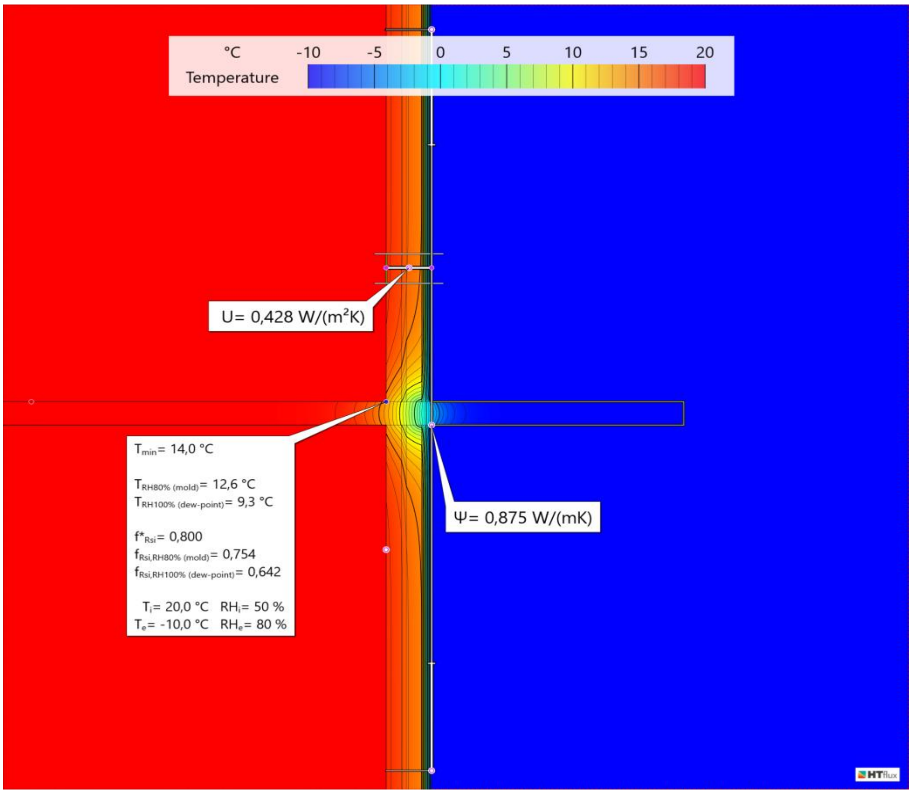


Figure 21: Temperature.

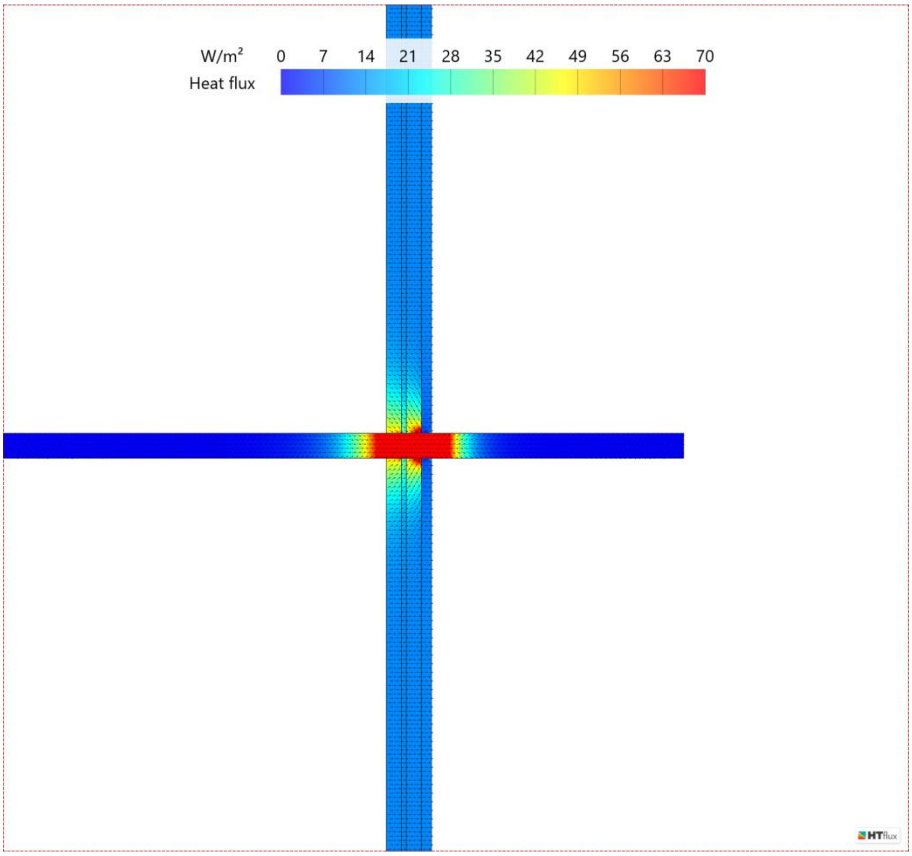


Figure 22: Heat flux.

As it was mentioned before, in conventional existing buildings it is impossible to fully abolish thermal bridges but using simple solutions their effect can be minimized. In this particular balcony, the solution is to insulate both sides of the balcony with 5cm of high density insulation (ex. EPS 200).

By implementing this measure, a thermal bridge with a Psi-value of 0,322W/mK occurs, which is more than two times lower than the uninsulated detail. Moreover, concerning the potential condensation, the minimum internal temperature is 16,9°C and it is not possible for mould to be formed.

The solution is shown in the following figures.

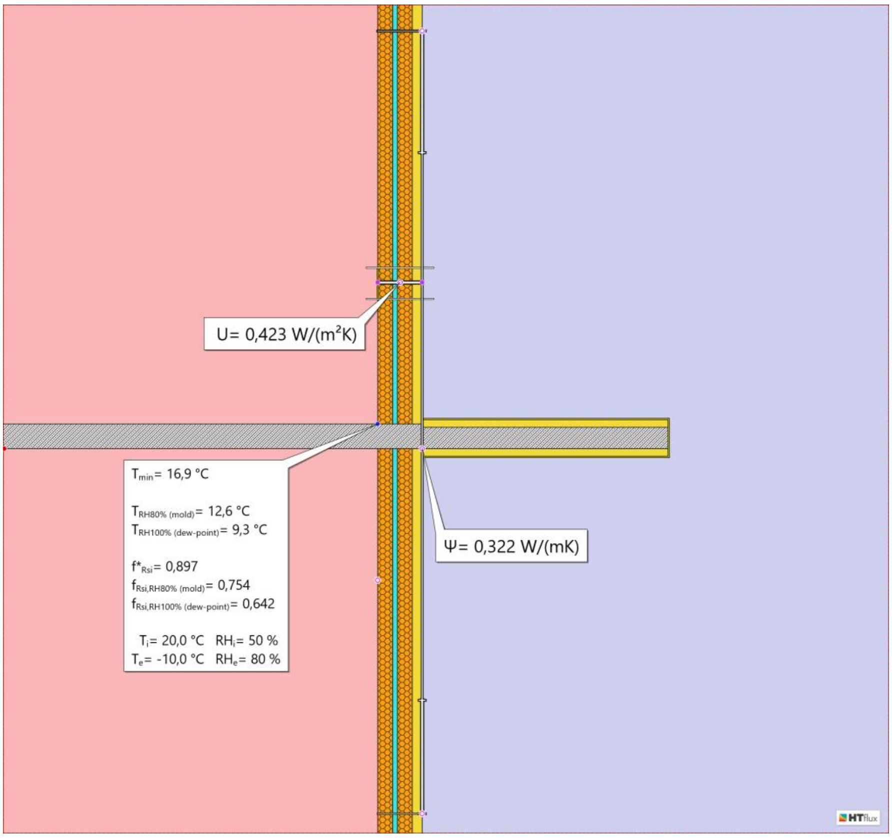


Figure 23: Materials used.

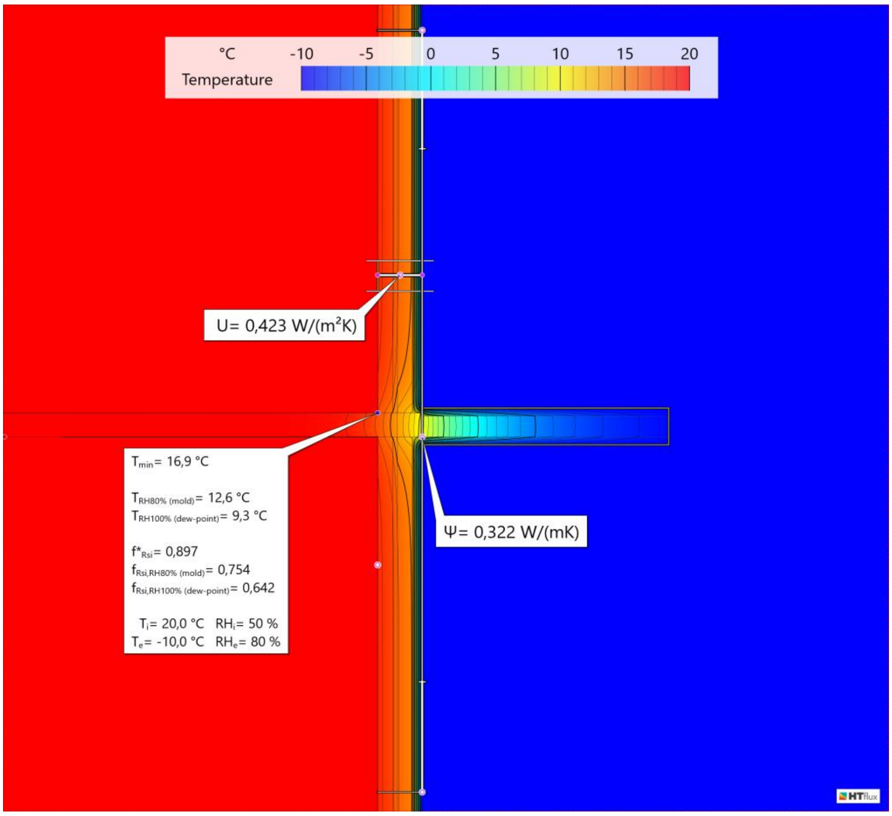


Figure 24: Temperature.

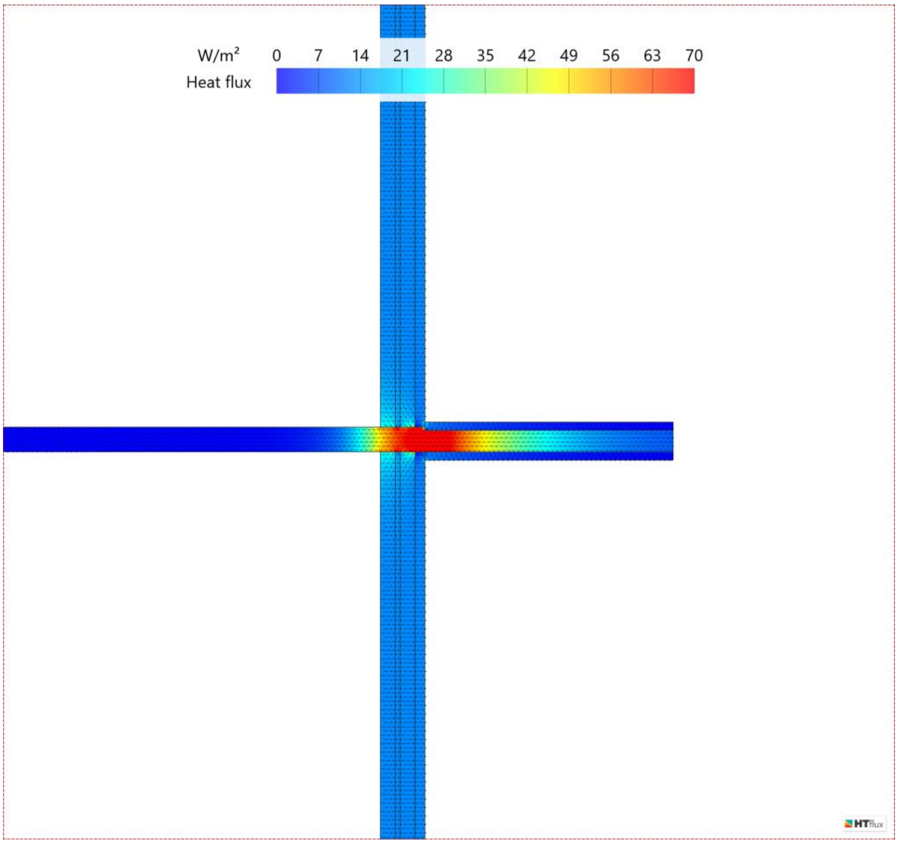


Figure 25: Heat flux.

- **Parapet**: Parapets exist in almost every conventional multifamily house in Greece. The parapets are building elements which are not a part of the thermal envelope. However, their presence causes an interruption of the roof insulation and thus their influence on the heat losses cannot be neglected.

  Based on the calculations conducted for the aforementioned elements, the thermal bridge value is Ψ = 1,00 W/mK, which will result in significant heat losses. The internal surface temperature is 6,8℃ which is much lower than the critical temperature of 12,6℃. During the design process, such value is not acceptable as it is indicative of condensation formation in the internal corner which is threatening both for building and the users (figure 29).

Figure 26: Retroffiting without taking into consideration the thermal bridges.

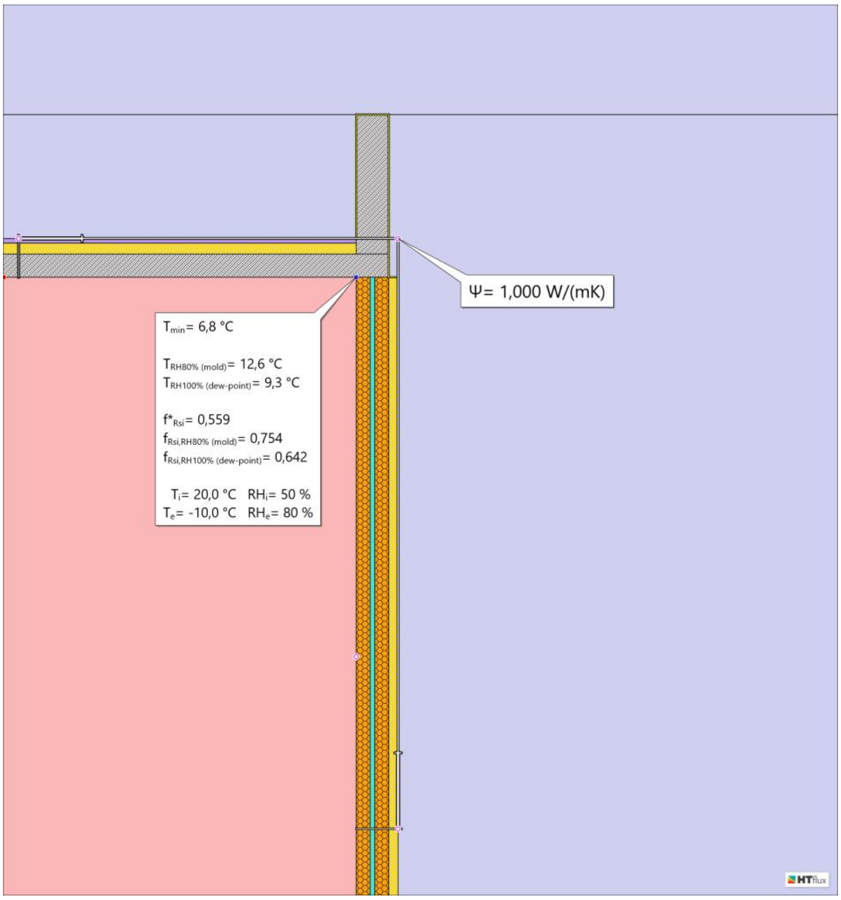


Figure 27: Materials used.

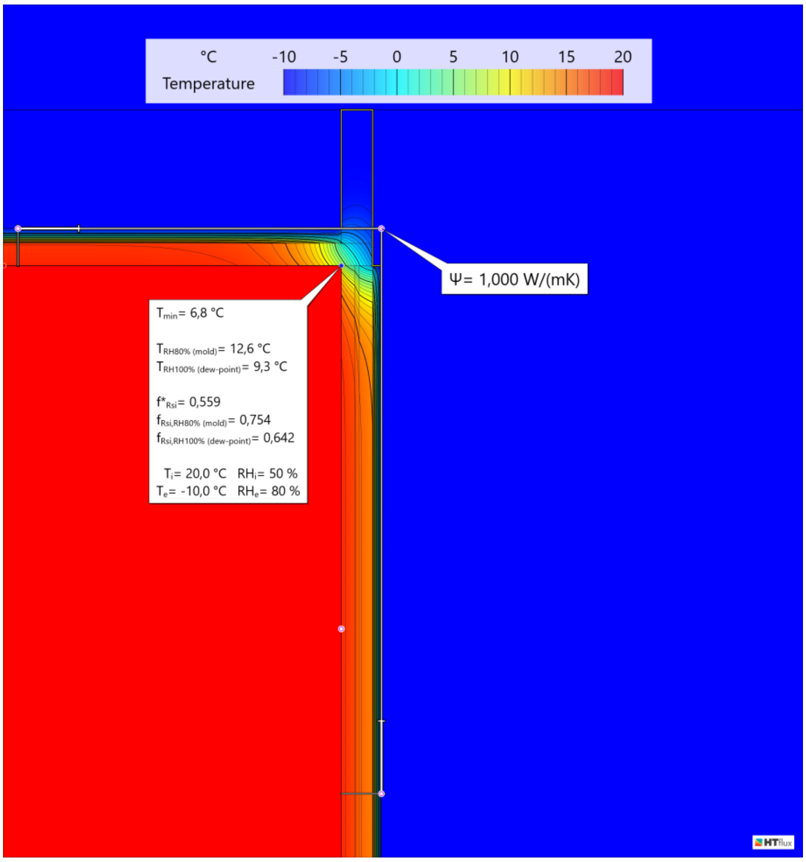


Figure 28: Temperature.

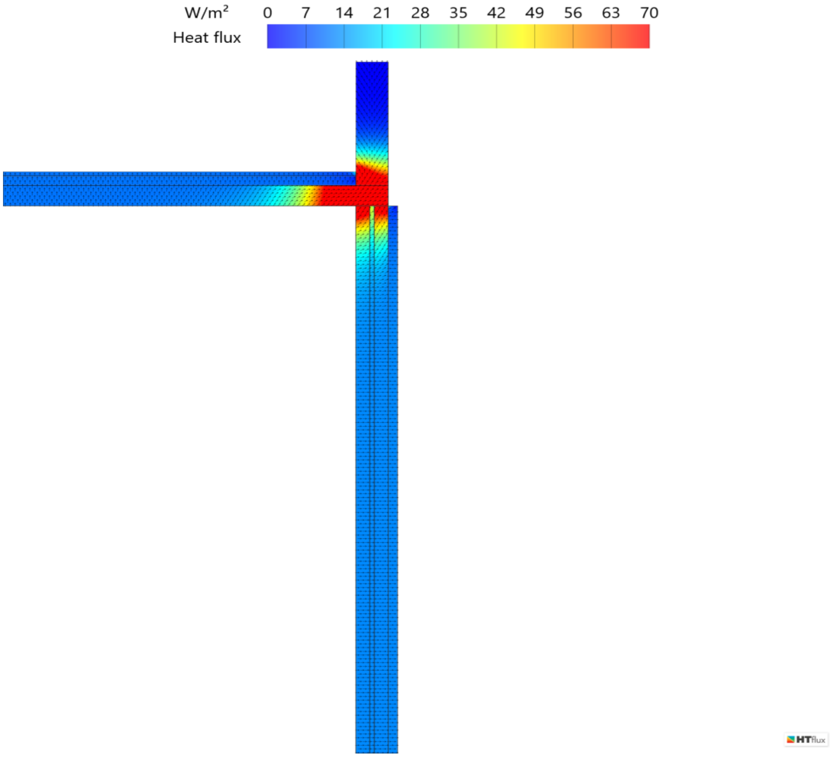


Figure 29: Heat flux.

The simplest and most cost-effective measure is to insulate the whole parapet by continuing the external insulation. By implementing a 6cm insulation around the whole perimeter of the parapet, a Psi-value of 0,216W/mK is obtained, which is five times lower than the uninsulated detail. Moreover, concerning the potential condensation formation, this will be prevented since the minimum internal surface temperature is 14,2℃.
The solution is shown in the following figures.

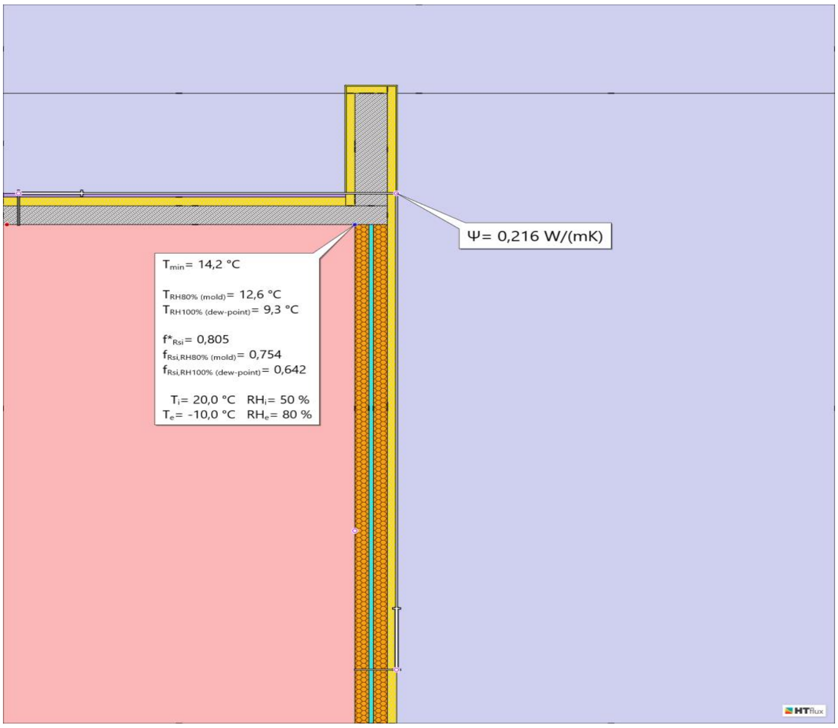


Figure 30: Materials used.

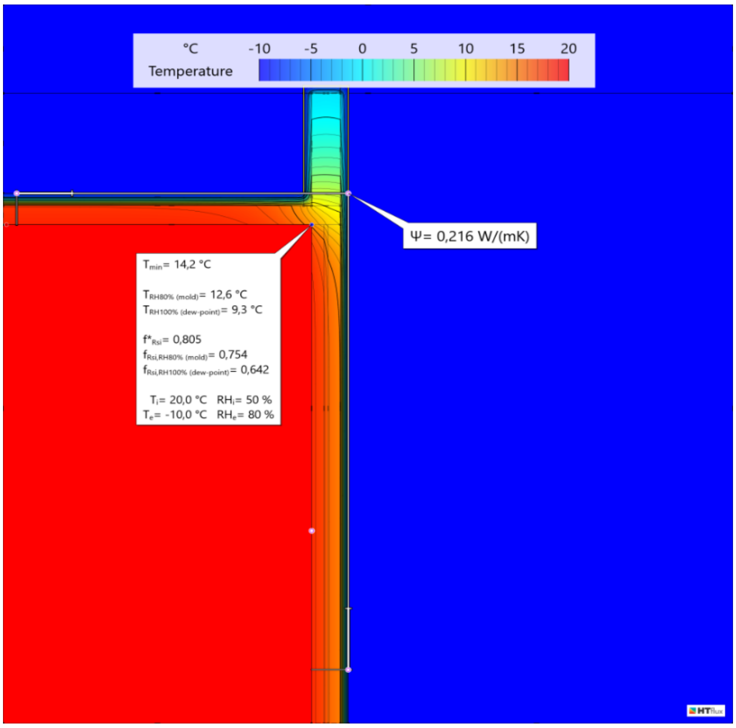


Figure 31: Temperature.

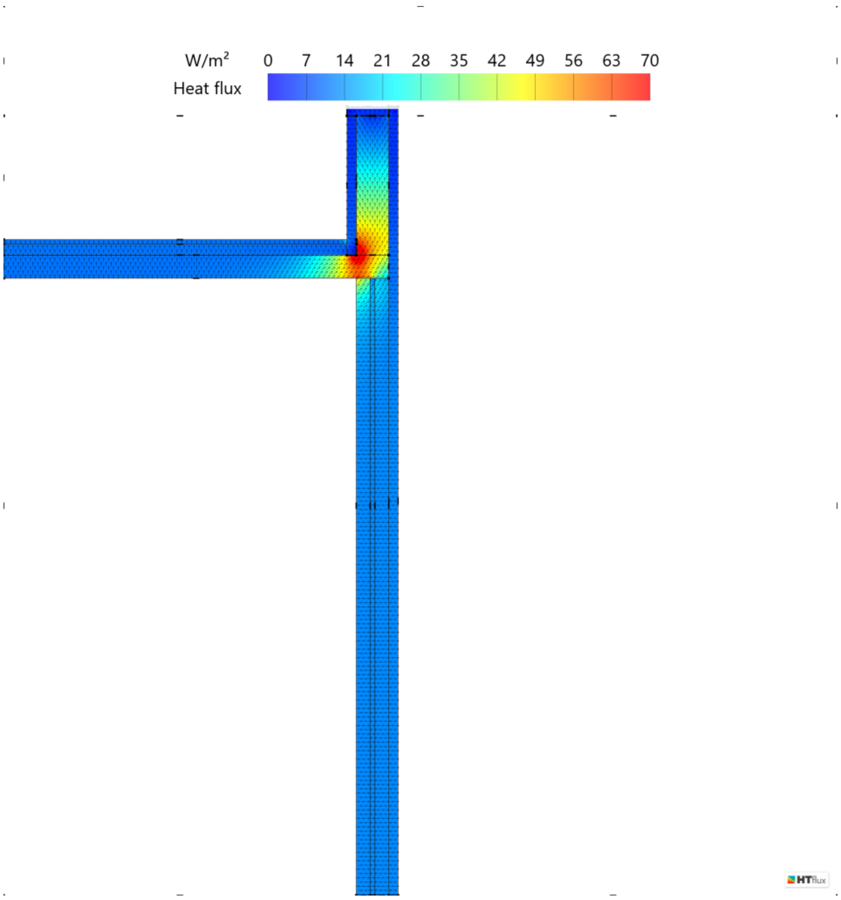


Figure 32: Heat flux.

These two are the main thermal bridge cases that we are facing in this project and they are easily minimized.

2.2.4. AIRTIGHTNESS

Airtightness is the cheapest and most energy-effective measure for the modification of a conventional building to a Passive House. Especially in Greece, where in brick-concrete constructions, an internal layer of plaster is mandatory and since plaster is an airtight material, the only additional cost is the airtightness tapes applied on the perimeter of the windows before the installation (figure 36).

Figure 33: Window installation in a passive house.

As it was mentioned in chapter 7.1.5., airtightness is one of the basic principles to achieve a Passive House. The air change rate per hour should be under 0,6 h^{-1} in a new construction and under 1 h^{-1} in retrofits. The airtightness of a building is measurable by the means of pressurization test and the most common test is the Blowerdoor Test. It is based on the principle of creating either a positive or a negative pressure of 50 Pa differential between the inside and the outside. Taking into account the overall volume of the building and the time required for the differential pressure to be eliminated, the air change rate of the building is accurately defined.

Figure 34: Blowerdoor test.

2.2.5. MECHANICAL VENTILATION WITH HEAT RECOVERY

A key element of a Passive house is the mechanical ventilation with heat (energy) recovery (MVHR); providing 100% fresh air all year round, for a healthy indoor environment, with high levels (up to 90%) of heat and energy recovery. The mechanical ventilation unit operates in a completely balanced way (equal amount of fresh air in to exhaust air out). This helps to reduce dramatically the space heating and cooling requirements, whilst providing the highest levels of comfort.

MVHR is one of the five pillars of Passive House, because there is a big need of fresh air due to the very airtight thermal envelope. The building should be ventilated, but without losing the heat in winter and the coolness in summer, while offering the necessary indoor air quality (IAQ).

In this particular study one MVHR with a heat exchanger up to 85% will be installed to each floor.

2.2.6. HEATING/ COOLING CARRIER – DHW – ELECTRICITY

The demand of heating and cooling in a Passive House is very low compared to conventional buildings. The heating and the cooling load is less than $10W/m^2$, therefore one fan coil in each apartment is enough to cover all the requirements. The distribution will be achieved through a canal system or alternatively a heat pump can be combined the MVHR.

Regarding the domestic hot water and the electricity systems, no measures will be implemented.

Options of night bypass cooling, heating/cooling via heat pump are available.

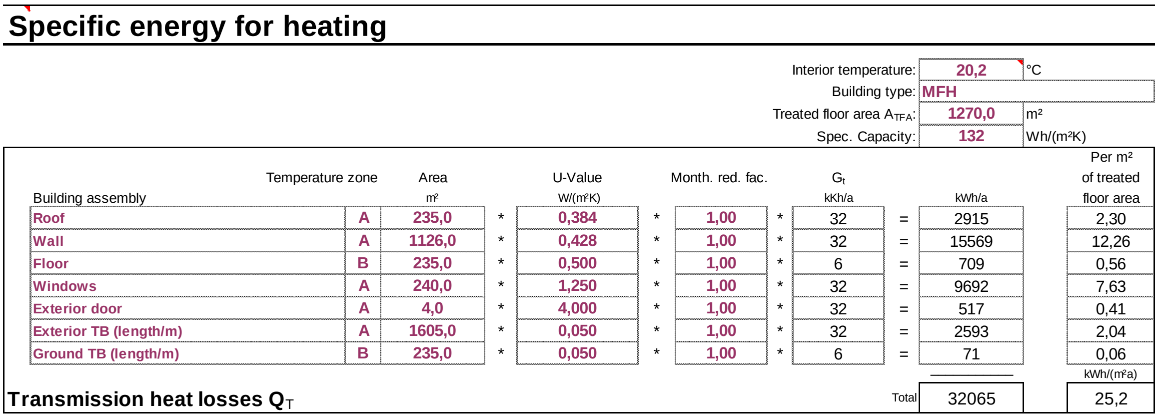
2.2.7. HEATING PERIOD

The detailed energy demand for one of these buildings is calculated according to EN ISO 13790 with same formulas as in Passive House Planning Package (PHPP) following the same procedure as in chapter 7.1.7.

In figure 38, the U values of the different building assemblies are defined and the total transmission heat losses **Q_T** through the building envelope are calculated as **25,2kWh/m^{2}a**.

The ventilation heat losses **Q_v** due to infiltration and the lack of a good airtightness level, which account for **3,3kWh/m^{2}a,** are presented in figure 39. The overall heat losses **Q_L** are **28,5kWh/m^{2}a**.

In figure 40, the solar heat gains **Q_S** **(34,8kWh/m^{2}a),** the internal heat gains **Q_I** **(12kWh/m^{2}a)**, the total heat gains **Q_G** **(39,8kWh/m^{2}a)** are presented. Finally, the annual heating demand **Q_H** **(74kWh/m^{2}a)** of this particular building can be identified on the same figure.

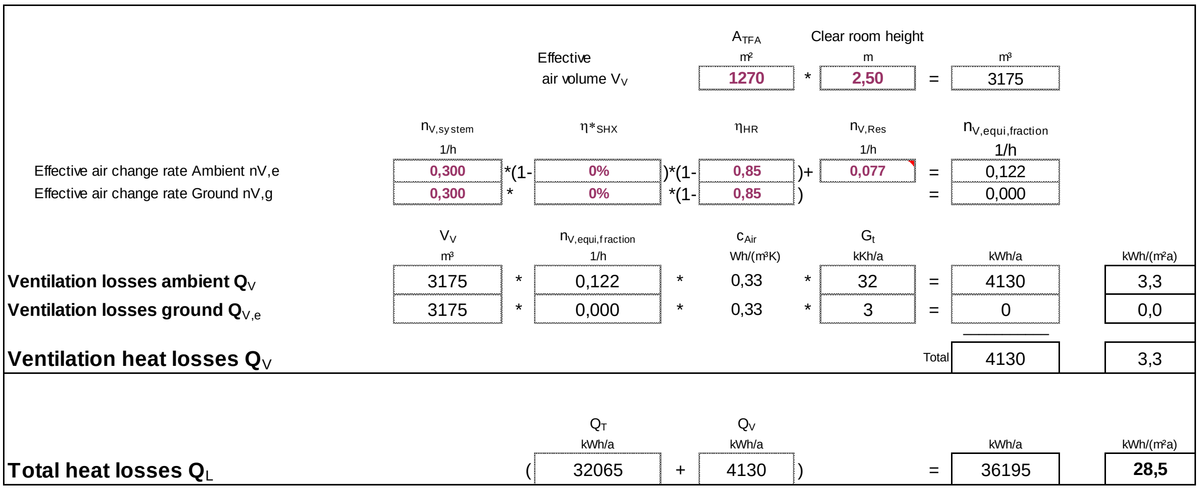


Specific energy for heating

Interior temperature:	20,2	°C
Building type:	MFH	
Treated floor area A_{TFA}:	1270,0	m²
Spec. Capacity:	132	Wh/(m²K)

Building assembly	Temperature zone	Area m²		U-Value W/(m²K)		Month. red. fac.		G_t kKh/a		kWh/a	Per m² of treated floor area
Roof	A	235,0	*	0,384	*	1,00	*	32	=	2915	2,30
Wall	A	1126,0	*	0,428	*	1,00	*	32	=	15569	12,26
Floor	B	235,0	*	0,500	*	1,00	*	6	=	709	0,56
Windows	A	240,0	*	1,250	*	1,00	*	32	=	9692	7,63
Exterior door	A	4,0	*	4,000	*	1,00	*	32	=	517	0,41
Exterior TB (length/m)	A	1605,0	*	0,050	*	1,00	*	32	=	2593	2,04
Ground TB (length/m)	B	235,0	*	0,050	*	1,00	*	6	=	71	0,06
											kWh/(m²a)
Transmission heat losses Q_T									Total	32065	25,2

Figure 35: Transmission heat losses.



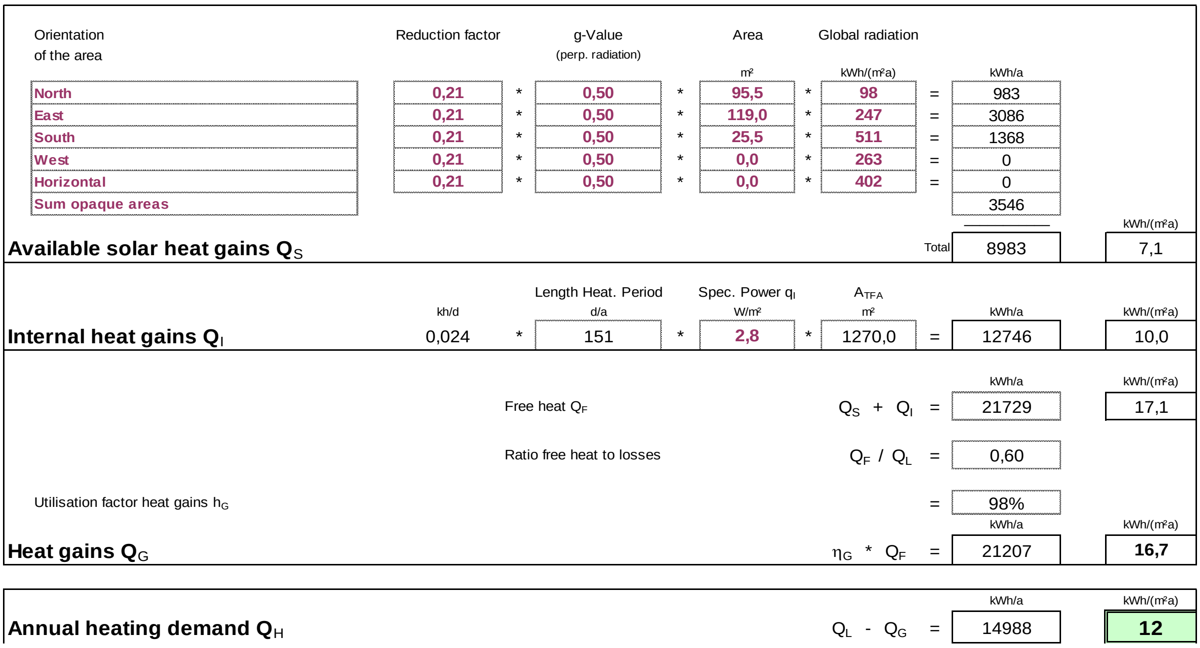
	A_{TFA} m²		Clear room height m		m³
Effective air volume V_V	1270	*	2,50	=	3175

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective air change rate Ambient nV,e	0,300	*(1-	0%	)*(1-	0,85	)+	0,077	=	0,122
Effective air change rate Ground nV,g	0,300	*	0%	*(1-	0,85	)		=	0,000

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation losses ambient Q_V	3175	*	0,122	*	0,33	*	32	=	4130	3,3
Ventilation losses ground $Q_{V,e}$	3175	*	0,000	*	0,33	*	3	=	0	0,0
Ventilation heat losses Q_V								Total	4130	3,3

		Q_T kWh/a		Q_V kWh/a			kWh/a	kWh/(m²a)
Total heat losses Q_L	(	32065	+	4130	)	=	36195	**28,5**

Figure 36: Ventilation heat losses – total heat losses.



Orientation of the area	Reduction factor		g-Value (perp. radiation)		Area m²		Global radiation kWh/(m²a)		kWh/a	kWh/(m²a)
North	0,21	*	0,50	*	95,5	*	98	=	983	
East	0,21	*	0,50	*	119,0	*	247	=	3086	
South	0,21	*	0,50	*	25,5	*	511	=	1368	
West	0,21	*	0,50	*	0,0	*	263	=	0	
Horizontal	0,21	*	0,50	*	0,0	*	402	=	0	
Sum opaque areas									3546	
Available solar heat gains Q_S								Total	8983	7,1

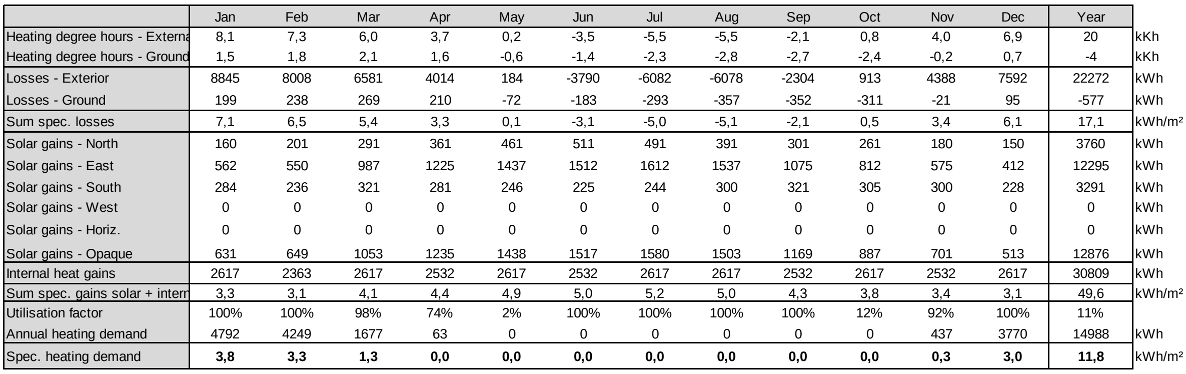
	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal heat gains Q_I	0,024	*	151	*	2,8	*	1270,0	=	12746	10,0

			kWh/a	kWh/(m²a)
Free heat Q_F	Q_S + Q_I	=	21729	17,1
Ratio free heat to losses	Q_F / Q_L	=	0,60	
Utilisation factor heat gains h_G		=	98%	
Heat gains Q_G	η_G * Q_F	=	21207	**16,7**

			kWh/a	kWh/(m²a)
Annual heating demand Q_H	Q_L - Q_G	=	14988	**12**

Figure 37: Heat gains – annual heating demand.

The monthly specific heating demand is calculated concerning different factors and the climate data of Athens. The results of this particular building are shown in figure 41.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating degree hours - Externa	8,1	7,3	6,0	3,7	0,2	-3,5	-5,5	-5,5	-2,1	0,8	4,0	6,9	20	kKh
Heating degree hours - Ground	1,5	1,8	2,1	1,6	-0,6	-1,4	-2,3	-2,8	-2,7	-2,4	-0,2	0,7	-4	kKh
Losses - Exterior	8845	8008	6581	4014	184	-3790	-6082	-6078	-2304	913	4388	7592	22272	kWh
Losses - Ground	199	238	269	210	-72	-183	-293	-357	-352	-311	-21	95	-577	kWh
Sum spec. losses	7,1	6,5	5,4	3,3	0,1	-3,1	-5,0	-5,1	-2,1	0,5	3,4	6,1	17,1	kWh/m²
Solar gains - North	160	201	291	361	461	511	491	391	301	261	180	150	3760	kWh
Solar gains - East	562	550	987	1225	1437	1512	1612	1537	1075	812	575	412	12295	kWh
Solar gains - South	284	236	321	281	246	225	244	300	321	305	300	228	3291	kWh
Solar gains - West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar gains - Opaque	631	649	1053	1235	1438	1517	1580	1503	1169	887	701	513	12876	kWh
Internal heat gains	2617	2363	2617	2532	2617	2532	2617	2617	2532	2617	2532	2617	30809	kWh
Sum spec. gains solar + intern	3,3	3,1	4,1	4,4	4,9	5,0	5,2	5,0	4,3	3,8	3,4	3,1	49,6	kWh/m²
Utilisation factor	100%	100%	98%	74%	2%	100%	100%	100%	100%	12%	92%	100%	11%	
Annual heating demand	4792	4249	1677	63	0	0	0	0	0	0	437	3770	14988	kWh
Spec. heating demand	**3,8**	**3,3**	**1,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,3**	**3,0**	**11,8**	kWh/m²

Figure 38: Monthly specific heating demand.

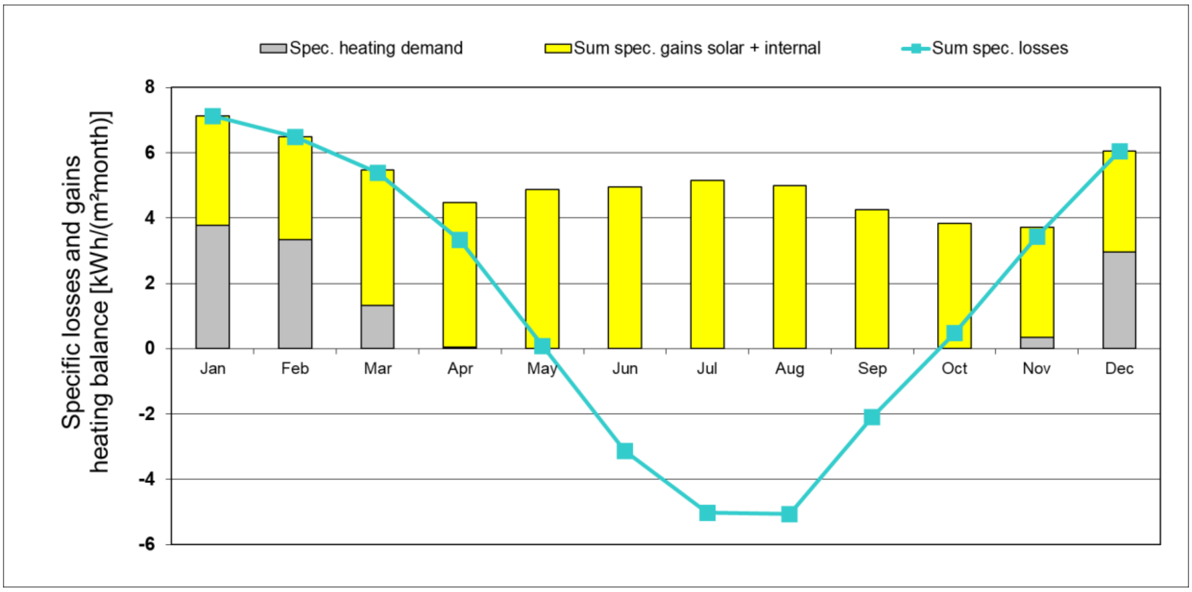


Figure 39: Monthly heating balance.

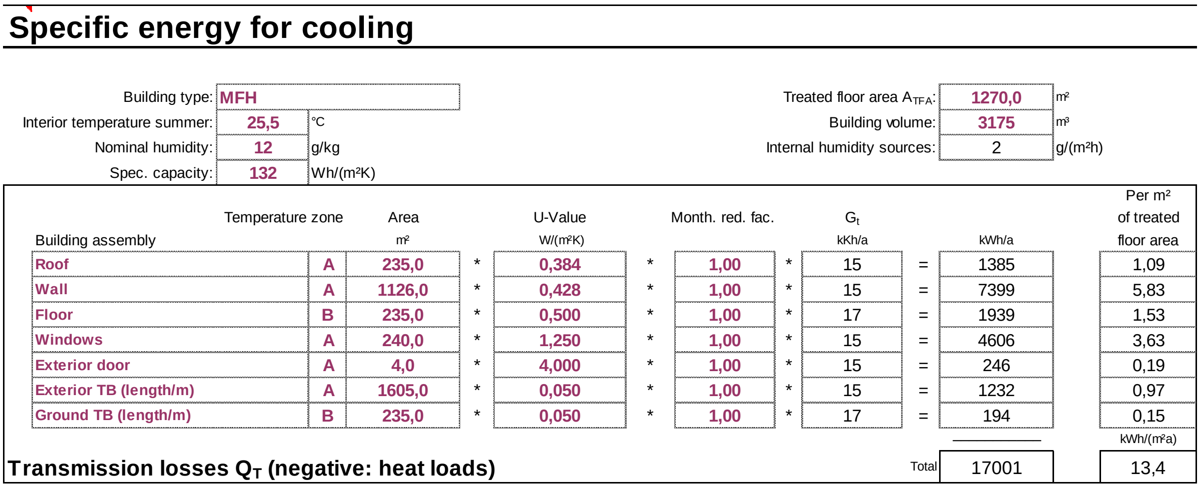
2.2.8. COOLING PERIOD

The same procedure described for the heating period was followed for the case of the cooling period for the same building of the neighbourhood.

The transmission losses **Q_T are 13,4kWh/m²a**, the ventilation heat losses **Q_V are 8,3kWh/m²a** and the total heat losses **Q_L are 21,7kWh/m²a (**figure 43,44**).**

The available solar heat gains **Q_S are 10,6kWh/m²a,** the Internal heat gains **Q_I are 14,2 kWh/m²a** and the total Heat Loads **Q_F are 24,9 kWh/m²a** (figure 45).

The results are the useful heat losses **$Q_{V,n}$ (10,5kWh/m²a)** and the useful cooling demand **Q_K (14kWh/m²a)** (figure 46)

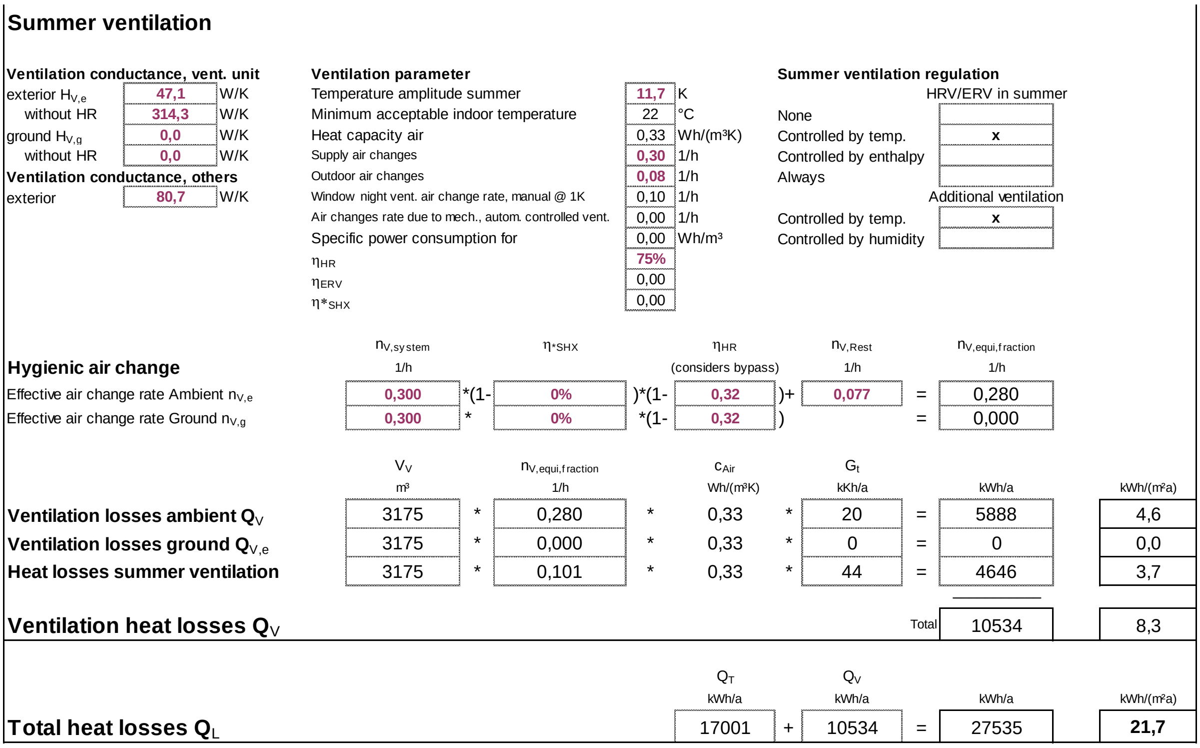


Specific energy for cooling

Building type:	MFH		Treated floor area A_{TFA}:	1270,0 m²
Interior temperature summer:	25,5	°C	Building volume:	3175 m³
Nominal humidity:	12	g/kg	Internal humidity sources:	2 g/(m²h)
Spec. capacity:	132	Wh/(m²K)		

Building assembly	Temperature zone	Area m²		U-Value W/(m²K)		Month. red. fac.		G_t kKh/a		kWh/a	Per m² of treated floor area
Roof	A	235,0	*	0,384	*	1,00	*	15	=	1385	1,09
Wall	A	1126,0	*	0,428	*	1,00	*	15	=	7399	5,83
Floor	B	235,0	*	0,500	*	1,00	*	17	=	1939	1,53
Windows	A	240,0	*	1,250	*	1,00	*	15	=	4606	3,63
Exterior door	A	4,0	*	4,000	*	1,00	*	15	=	246	0,19
Exterior TB (length/m)	A	1605,0	*	0,050	*	1,00	*	15	=	1232	0,97
Ground TB (length/m)	B	235,0	*	0,050	*	1,00	*	17	=	194	0,15
											kWh/(m²a)
Transmission losses Q_T (negative: heat loads)									Total	17001	13,4

Figure 40: Transmission heat losses.



Summer ventilation

Ventilation conductance, vent. unit

exterior $H_{V,e}$	47,1	W/K
without HR	314,3	W/K
ground $H_{V,g}$	0,0	W/K
without HR	0,0	W/K

Ventilation conductance, others

exterior	80,7	W/K

Ventilation parameter

Temperature amplitude summer	11,7	K
Minimum acceptable indoor temperature	22	°C
Heat capacity air	0,33	Wh/(m³K)
Supply air changes	0,30	1/h
Outdoor air changes	0,08	1/h
Window night vent. air change rate, manual @ 1K	0,10	1/h
Air changes rate due to mech., autom. controlled vent.	0,00	1/h
Specific power consumption for	0,00	Wh/m³
η_{HR}	75%	
η_{ERV}	0,00	
η^*_{SHX}	0,00	

Summer ventilation regulation

	HRV/ERV in summer
None	
Controlled by temp.	x
Controlled by enthalpy	
Always	
	Additional ventilation
Controlled by temp.	x
Controlled by humidity	

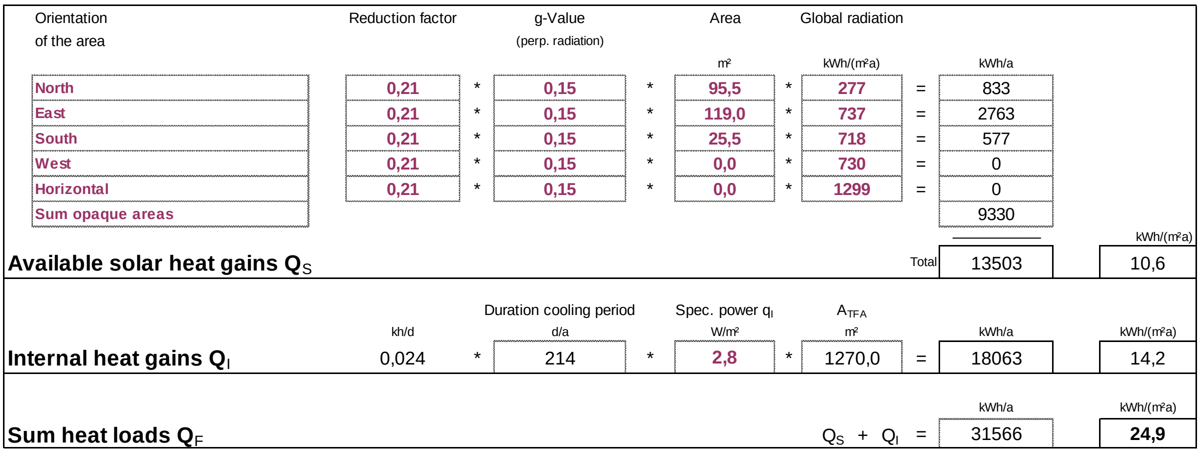
Hygienic air change

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR} (considers bypass)		$n_{V,Rest}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective air change rate Ambient $n_{V,e}$	0,300	*(1-	0%	)*(1-	0,32	)+	0,077	=	0,280
Effective air change rate Ground $n_{V,g}$	0,300	*	0%	*(1-	0,32	)		=	0,000

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation losses ambient Q_V	3175	*	0,280	*	0,33	*	20	=	5888	4,6
Ventilation losses ground $Q_{V,e}$	3175	*	0,000	*	0,33	*	0	=	0	0,0
Heat losses summer ventilation	3175	*	0,101	*	0,33	*	44	=	4646	3,7
Ventilation heat losses Q_V								Total	10534	8,3

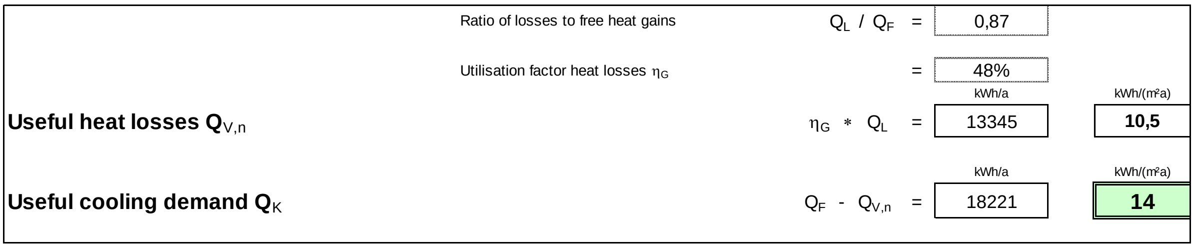
	Q_T kWh/a		Q_V kWh/a		kWh/a	kWh/(m²a)
Total heat losses Q_L	17001	+	10534	=	27535	**21,7**

Figure 41: Ventilation heat losses – total heat losses.



Orientation of the area	Reduction factor		g-Value (perp. radiation)		Area		Global radiation			
					m²		kWh/(m²a)		kWh/a	
North	0,21	*	0,15	*	95,5	*	277	=	833	
East	0,21	*	0,15	*	119,0	*	737	=	2763	
South	0,21	*	0,15	*	25,5	*	718	=	577	
West	0,21	*	0,15	*	0,0	*	730	=	0	
Horizontal	0,21	*	0,15	*	0,0	*	1299	=	0	
Sum opaque areas									9330	
										kWh/(m²a)
Available solar heat gains Q_S								Total	13503	10,6
			Duration cooling period		Spec. power q_I		A_{TFA}			
	kh/d		d/a		W/m²		m²		kWh/a	kWh/(m²a)
Internal heat gains Q_I	0,024	*	214	*	2,8	*	1270,0	=	18063	14,2
									kWh/a	kWh/(m²a)
Sum heat loads Q_F							Q_S + Q_I	=	31566	**24,9**

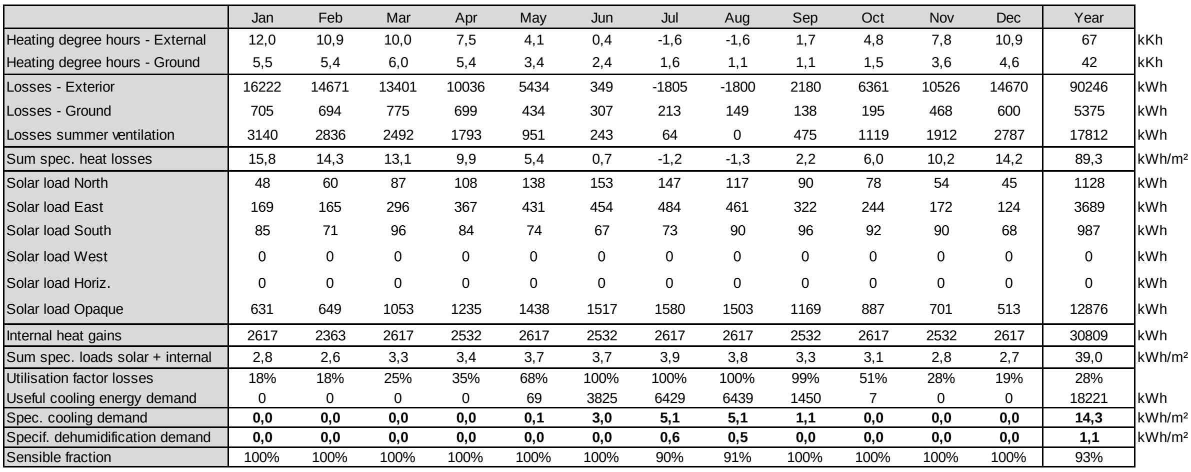
Figure 42: Heat gains – heat loads.



	Ratio of losses to free heat gains	Q_L / Q_F	=	0,87	
	Utilisation factor heat losses η_G		=	48%	
				kWh/a	kWh/(m²a)
Useful heat losses $Q_{V,n}$		η_G * Q_L	=	13345	**10,5**
				kWh/a	kWh/(m²a)
Useful cooling demand Q_K		Q_F - $Q_{V,n}$	=	18221	**14**

Figure 43: Useful heat losses – useful cooling demand.

Monthly calculations are made by taking into consideration different factors, as presented in the next figure (47).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating degree hours - External	12,0	10,9	10,0	7,5	4,1	0,4	-1,6	-1,6	1,7	4,8	7,8	10,9	67	kKh
Heating degree hours - Ground	5,5	5,4	6,0	5,4	3,4	2,4	1,6	1,1	1,1	1,5	3,6	4,6	42	kKh
Losses - Exterior	16222	14671	13401	10036	5434	349	-1805	-1800	2180	6361	10526	14670	90246	kWh
Losses - Ground	705	694	775	699	434	307	213	149	138	195	468	600	5375	kWh
Losses summer ventilation	3140	2836	2492	1793	951	243	64	0	475	1119	1912	2787	17812	kWh
Sum spec. heat losses	15,8	14,3	13,1	9,9	5,4	0,7	-1,2	-1,3	2,2	6,0	10,2	14,2	89,3	kWh/m²
Solar load North	48	60	87	108	138	153	147	117	90	78	54	45	1128	kWh
Solar load East	169	165	296	367	431	454	484	461	322	244	172	124	3689	kWh
Solar load South	85	71	96	84	74	67	73	90	96	92	90	68	987	kWh
Solar load West	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar load Opaque	631	649	1053	1235	1438	1517	1580	1503	1169	887	701	513	12876	kWh
Internal heat gains	2617	2363	2617	2532	2617	2532	2617	2617	2532	2617	2532	2617	30809	kWh
Sum spec. loads solar + internal	2,8	2,6	3,3	3,4	3,7	3,7	3,9	3,8	3,3	3,1	2,8	2,7	39,0	kWh/m²
Utilisation factor losses	18%	18%	25%	35%	68%	100%	100%	100%	99%	51%	28%	19%	28%	
Useful cooling energy demand	0	0	0	0	69	3825	6429	6439	1450	7	0	0	18221	kWh
Spec. cooling demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,1**	**3,0**	**5,1**	**5,1**	**1,1**	**0,0**	**0,0**	**0,0**	**14,3**	kWh/m²
Specif. dehumidification demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,6**	**0,5**	**0,0**	**0,0**	**0,0**	**0,0**	**1,1**	kWh/m²
Sensible fraction	100%	100%	100%	100%	100%	100%	90%	91%	100%	100%	100%	100%	93%	

Figure 44: Monthly calculation - cooling demand.

The cooling period has a duration of five months and lasts from May to September according to the graph below (figure 48).

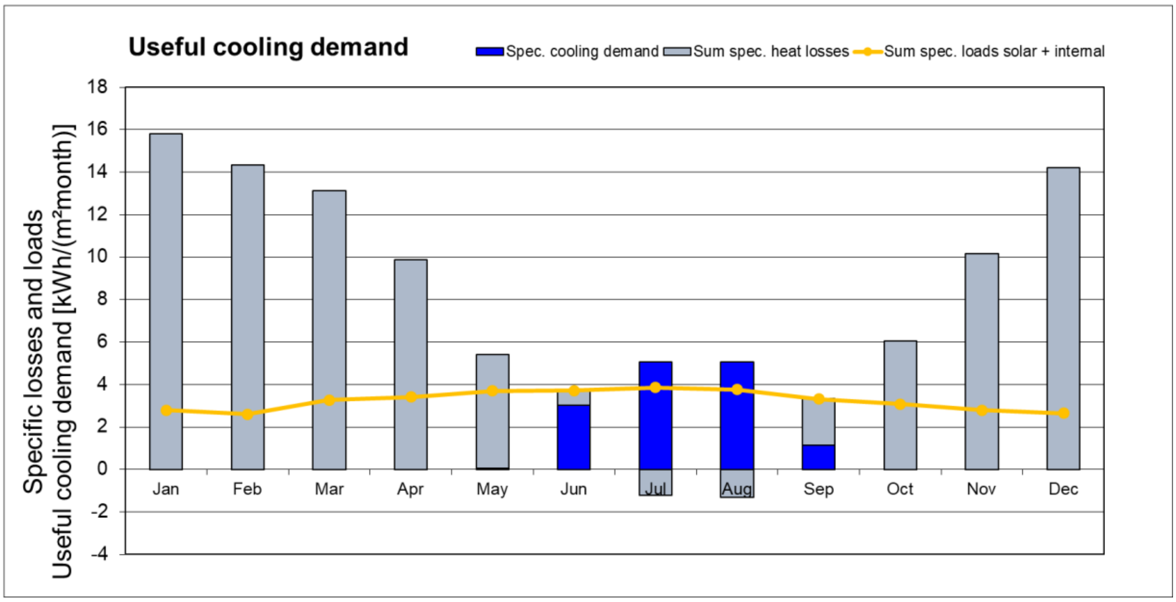


Figure 45: Useful cooling demand.

3. AUSTRIA

3.1. SUMMARY

In this study, a building district in St. Johann in Tirol with currently a total of 29 buildings and a total treated floor area of 22993 m² was investigated by the use of the districtPH tool. Different scenarios for its development until the year 2072 were evaluated.

The focus was on the heat supply, especially with regard to the future supply of district heating. In addition, an estimation of the PV potential on the roof surfaces of the investigated district was also carried out. The development of future GHG emissions was estimated for two different renovation scenarios (OIB and EnerPHit). It was shown that the long-term GHG emissions in the OIB scenario are more than 2.5 times the emissions of the EnerPHit scenario. Highly energy-efficient buildings presumably also open up the possibility of connecting additional neighborhoods to district heating without additional capacity expansion in the district heating company's heat generation. However, due to the very limited area under consideration in this study, this statement can neither be made with certainty nor generalized, but it does demonstrate the far-reaching opportunities and advantages of comprehensive high-efficiency EnerPHit refurbishment, even in rural areas.

3.2. PRESENT STATE OF THE DISTRICT

In the course of the outPHit project, three multi-family buildings in St. Johann in Tirol are being refurbished. Neue Heimat Tirol, as outPHit project partner, has developed a renovation concept for the three buildings that includes a connection to district heating and the integration of PV systems on the roofs of the buildings.

In the course of the expected increasing sector coupling of heat and electricity, the University of Innsbruck is investigating the district in which the three buildings, called Südtirolersiedlung in St. Johann in Tyrol in Austria, are located with the tool districtPH. Scenarios for the development of the heat and electricity demand are developed and presented in dependence of the renovation depth. In addition, the energy supply of the district and the potential of existing renewable energy sources are analysed.

Figure 46: OutPHit-Demonstration building of Neuen Heimat as part of the evaluated district. (©NHT/Malzer)

3.2.1. LOCATION AND SURROUNDINGS

St. Johann in Tirol is located in the Leukental valley in the Tiroler Unterland in Austria at an altitude of about 700 meters above sea level. The municipality is embedded in an alpine landscape, the typical temperatures are very low, especially in winter, which in combination with the surrounding shading leads to a comparatively high heating demand (Figure 50).

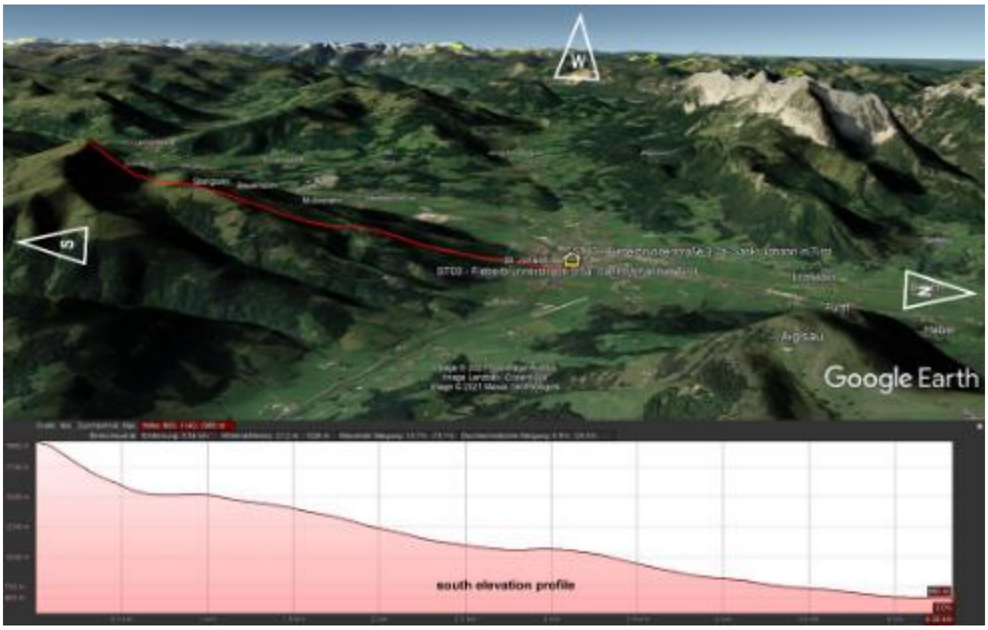


Figure 47: Surrounding and shading situation of St. Johann in Tirol.

St. Johann in Tirol is a community with about 10,000 inhabitants in a rural environment. The three demonstration buildings of Neue Heimat Tirol are located in the "Südtirolersiedlung" (Figure 48). It contains mainly houses built in the early 1960's for Italian guest workers.

Figure 48: St. Johann in Tirol and the evaluated district Südtirolersiedlung.

3.2.2. BUILDING STOCK

The choice of the area under consideration is depicted in Figure 49.

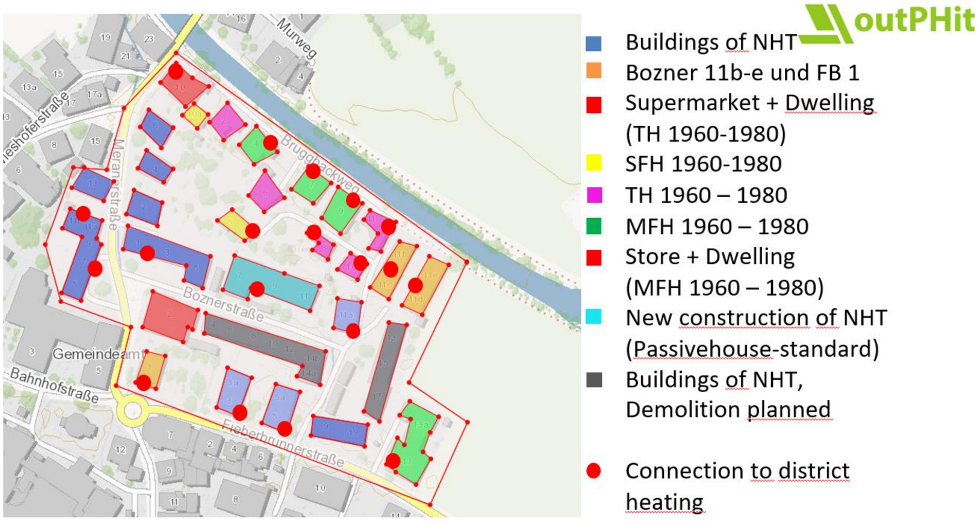


Figure 49: Evaluated district, building type and year of construction, connection to district heating. (Own representation, source of base layer map: www.tirolsolar.at)

The choice of the evaluated district falls on the Südtirolersiedlung. This brings the advantage that some buildings are owned by the outPHit project partner Neue Heimat Tirol and accordingly a lot of information about the buildings is available. The area thus comprises 29 buildings. Most of them are multi-family buildings, there are also smaller buildings and two retail spaces in the area under consideration.

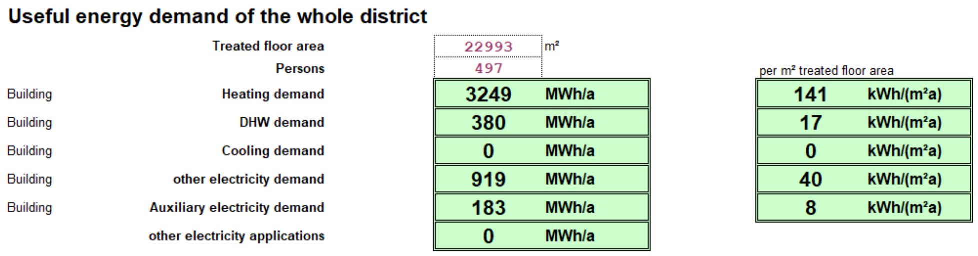
All buildings of Neue Heimat Tirol were considered as individual buildings in districtPH according to the available building data (thermal envelope, heating and domestic hot water production (DHW)). It is assumed that the demonstration buildings in outPHit are refurbished by the end of 2022.

The buildings at Boznerstraße 11 b-e (Bozner 11 b-e) and Fieberbrunnerstraße (FB 1) are visually very similar to the neighbouring buildings of Neue Heimat Tirol. Therefore, it is assumed for these buildings that the building data correspond to the nearest building marked in blue on the map. The gross floor area is measured based on the building exterior dimensions on the map, and the number of full stories is determined based on the windows. The conversion factor for the treated floor area is assumed to be 0.8.

The other buildings in the neighbourhood were assigned to the type buildings for Austria according to the districtPH calculation. For the age of the buildings, it is assumed that the district was built between 1960 and 1980. The treated floor area is determined in the same way as described above.

3.2.3. HEATING DEMAND

In the reference year 2022, the **heating demand** for the evaluated district is **3249 MWh.** This corresponds to **141 kWh/(m²a).** Added to this is the heat demand for hot water and electricity according to Figure 50.



Useful energy demand of the whole district

	Treated floor area	22993	m²		
	Persons	497		per m² treated floor area	
Building	Heating demand	3249	MWh/a	141	kWh/(m²a)
Building	DHW demand	380	MWh/a	17	kWh/(m²a)
Building	Cooling demand	0	MWh/a	0	kWh/(m²a)
Building	other electricity demand	919	MWh/a	40	kWh/(m²a)
Building	Auxiliary electricity demand	183	MWh/a	8	kWh/(m²a)
	other electricity applications	0	MWh/a		

Figure 50: Summary of the calculation results of the reference year 2022. (Screenshot from districtPH)

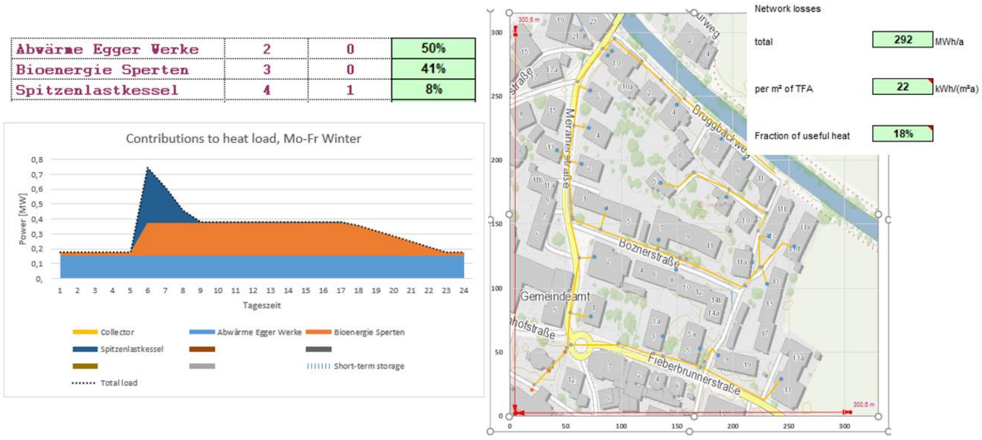
3.2.4. HEAT GENERATION

District heating

Figure 52 in Chapter 8.2.2. shows that a large part of the buildings in the area are already connected to the local district heating system. However, this does not mean that all apartments in the buildings under consideration are connected to district heating. For the calculation, the situation in the existing buildings with known heat generation is extrapolated for all buildings with district heating connection. The exceptions are the new construction and the outPHit demonstration buildings, which are completely connected to district heating.

After consultation with the district heating operator, it is not possible to map the real routes of the district heating pipelines for safety reasons. For this reason, only an exemplary network connecting the individual connection points is used in the calculation (see Figure Figure 51).

In the reference year, the **district heating demand** for heating and hot water in the considered area (including distribution losses in the network) is **1889 MWh.** The district heating demand in St. Johann in Tirol can be covered to a large extent by renewable energy. The waste heat of an industrial wood processing plant is available (approx. 50 % coverage of the annual energy demand of the district heating network). In addition, waste heat from a biomass power plant is fed into the district heating grid. The remaining heat demand is covered by a fossil fuel peak load boiler. The coverage of the district heating demand is shown schematically in Figure 51 for the type day winter working day from the calculation in districtPH. In addition, the shares of the heat generators in the generated annual energy quantity for the district heating network are shown.



Abwärme Egger Werke	2	0	50%
Bioenergie Sperten	3	0	41%
Spitzenlastkessel	4	1	8%

Network losses

total	292	MWh/a
per m² of TFA	22	kWh/(m²a)
Fraction of useful heat	18%	

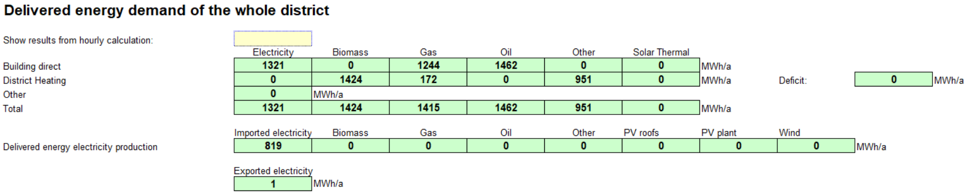
Figure 51: District heating generation in the reference year 2022. (Screenshot from districtPH)

Due to the high share of district heating generation in the heat quantity and the locally available waste heat potential, special attention is paid to the consideration of district heating in the further calculations. Since the entire district heating network is not represented in the calculation, the calculation results are only valid for the neighbourhood under consideration.

Decentralised heat generation

In the neighbourhood under consideration, the remaining heat demand is covered by heat generators installed in apartments or in central buildings. Gas boilers, oil boilers and direct electric heat generation are considered. The known buildings of Neue Heimat Tirol in the area under consideration are again used to estimate the coverage shares.

This results in the final energy demand of the district in 2022 by energy source, shown in Figure 52. This includes the amount of electricity consumed. Based on satellite photos, it is estimated that the photovoltaic power generation in the district is negligible in the reference year.



Delivered energy demand of the whole district

Show results from hourly calculation:

	Electricity	Biomass	Gas	Oil	Other	Solar Thermal	
Building direct	1321	0	1244	1462	0	0	MWh/a
District Heating	0	1424	172	0	951	0	MWh/a
Other	0	MWh/a					
Total	1321	1424	1415	1462	951	0	MWh/a

Deficit: 0 MWh/a

	Imported electricity	Biomass	Gas	Oil	Other	PV roofs	PV plant	Wind	
Delivered energy electricity production	819	0	0	0	0	0	0	0	MWh/a

Exported electricity
1 MWh/a

Figure 52: Final energy demand in the reference year 2022. (Screenshot from districtPH)

3.2.5. GREENHOUSEGAS EMISSIONS (GHG)

For the district under consideration, this results in greenhouse gas emissions of **1089 t CO_2 equivalent** in the reference year.

The conversion factors for primary energy and CO_2 for Austria (GEMIS, [Sinfonia 2018]), in particular for the amount of energy drawn from the electrical power grid in the reference year, were used.

3.3. REFURBISHMENT SCENARIOS

The assumptions for factors that influence the temporal development of the considered target variables in the district are explained below.

3.3.1. CALCULATION PERIODE AND NUMBER OF CALCULATION RUNS (MONTE-CARLO-SIMULATION)

The maximum possible period in districtPH of 50 years is selected as the period under consideration. Since the calculation is based on probabilities, all calculation results are presented as the average of 10 calculation runs (Monte Carlo simulation), unless otherwise specified.

3.3.2. LIVING AREA AND REDENSIFICATION

In the district under consideration, one building has already been demolished and a new building constructed in passive house quality (see Figure 49, marked in light blue). The original living area was increased by a factor of 2,6. For the buildings for which demolition is also planned (marked in black), it is assumed that the living area can be increased by the same factor. It is further assumed that the buildings will be demolished in 2026 and 2030, replaced in the same year with a new building in passive house quality and completely connected to district heating (heating and DHW).

As a result of the redensification, the treated floor area in the district increases from 22,993 m^2 in the starting year 2022 to 25,210 m^2 in 2030 and then remains constant until the end of the period under consideration in 2072.

3.3.3. COMPONENT LIFETIME

The time for replacement of a component or system becomes most probable at the end of its component life. The calculation is done according to districtPH logic using probabilities. For this purpose, the following component lifetimes are assumed in districtPH.

Component	Average lifetime
Wall	50 years
Floor	40 years
Roof	40 years
Window	30 years
Entrance door	30 years
Airtightness	40 years
Technical building equipment (Heating, DHW, Cooling)	30 years

Table 1: Average lifetime of building components (own estimate based on BBSR 2017 and BTE 2008)

3.3.4. COMPONENT QUALITY

The quality of the building envelope after refurbishment is crucial for reducing the energy demand in the district. Two scenarios are developed for this purpose.

For refurbishment according to national minimum requirements (OIB guidelines), it is assumed that the thermal transmittance values of the building components correspond to the minimum standard according to the German Energy Saving Regulation (EnEV). In contrast, the passive house standard for refurbishment (EnerPhit standard) is considered.

The component qualities shown indicate the most probable standard after refurbishment. In each case, a standard deviation of one quality step around the most probable standard is assumed according to districtPH calculation logic.

Component	**Reference quality Minimum standard** (room set temperature for heating >19°C)	**Quality according to Passivhouse Standard for refurbishment (EnerPHit)**
Wall	U = 0,28 W/(m^2*K)	U = 0,15 W/(m^2*K)
Floor	U = 0,35 W/(m^2*K)	U = 0,15 W/(m^2*K)
Roof	U = 0,2 W/(m^2*K)	U = 0,15 W/(m^2*K)
Window	U = 1,3 W/(m^2*K)	U = 0,8 W/(m^2*K)
Entrance door	U = 1,8 W/(m^2*K)	U = 0,15 W/(m^2*K)
Airtightness	n_{50} = 3 h^{-1}	n_{50} = 0,6 h^{-1}

Table 2: Component quality after refurbishment (Based on [EnEV 2014] and [PHI 2020])

Over time, the use of the minimum standard results in a reduction of the heating demand from 141 kWh/(m^{2}a) to approx. 50 kWh/(m^{2}a). It can be clearly seen that a large proportion of the reduction in heating demand is due to demolition and new construction to the Passive

House Standard by 2030 in both scenarios. Afterwards, there is a significant difference in between the scenario with minimum requirements and according to EnerPHit standard.

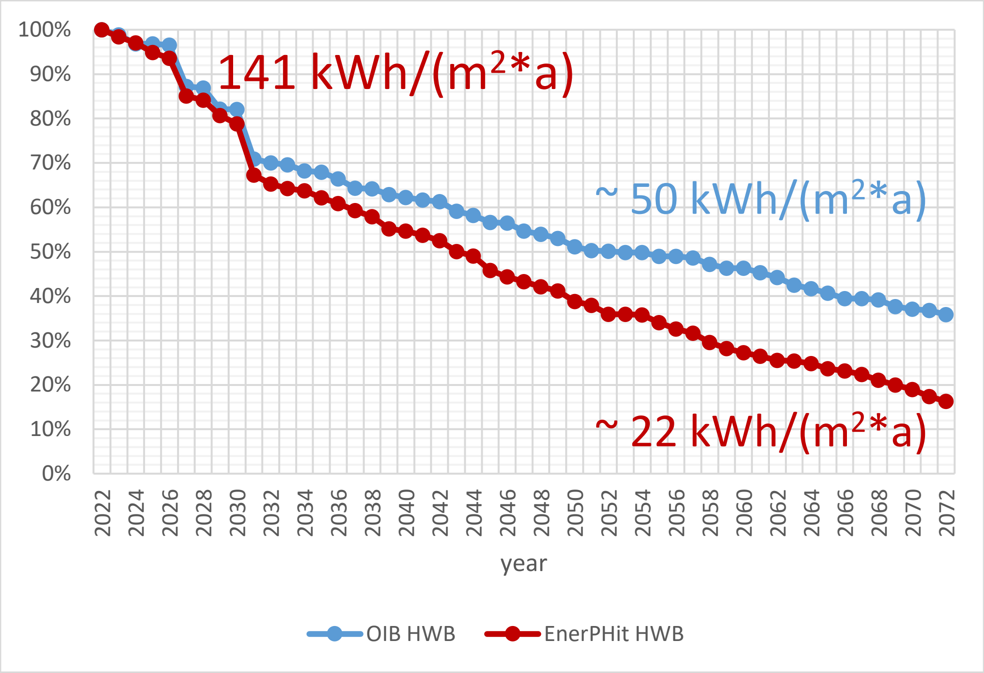


Figure 53: Heating demand over time as a function of the quality standard after refurbishment, specific heating demand at the beginning and end of the period under review. (Own representation)

3.3.5. EXCHANGE OF SYSTEMS FOR HEAT GENERATION FOR ROOM HEATING AND DHW

In order to investigate the best possible utilization of locally available renewable resources, the impact on the demand for energy from the district heating network will be investigated. Therefore, it is assumed that almost all heat generators for heating and hot water are replaced by connection to the district heating system at the end of their lifetime. The share of annual heat provided by the district heating network in relation to the total heat demand in the area under consideration is shown in Figure 54.

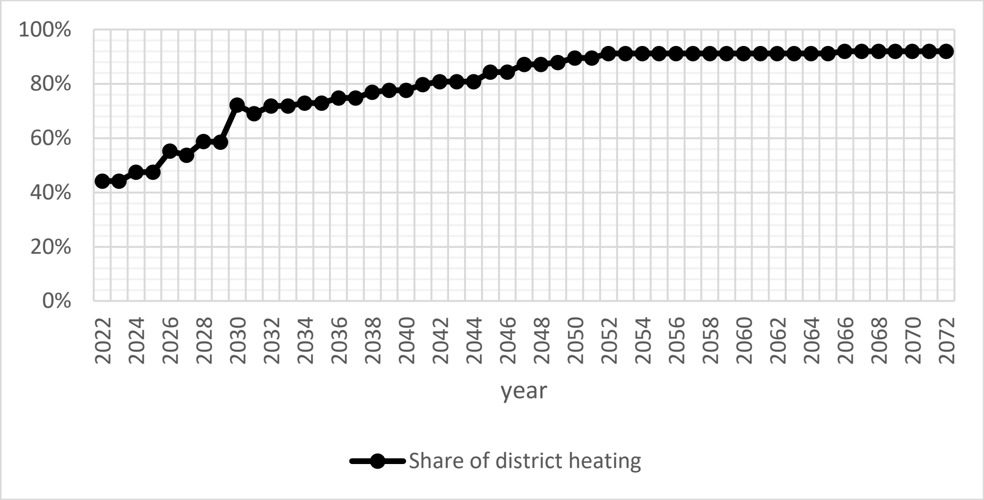


Figure 54: Share of district heating in heat supply (final energy for heating and hot water) over time (own representation)

3.3.6. DISTRICT HEATING GENERATION

In the reference year 2022, an annual energy quantity of just under 1900 MWh is available in the district heating network for the area under consideration. This amount of energy is largely generated from renewable sources (see Chapter 8.2.4.) Since industrial waste heat and a biomass power plant are involved, it can be assumed that the potential of these sources can be kept constant in the future. In Figure 55, this is indicated by the solid black line. Comparing the district heating potential with the amount of energy to be generated in the district heating network to supply the area (delivered final energy at the balance boundary of the buildings plus losses in the district heating network), it becomes clear that with a high energy efficiency standard, it is possible to connect almost all buildings in the district to the district heating network without tapping further renewable potentials or increasing the operating times of the peak load boiler. Furthermore, the difference between potential and consumption enables the expansion of district heating to further supply areas. Through an appropriate pricing scheme, the operation of the district heating network must remain economical with decreasing power density in the area under consideration and potential expansions.

Furthermore, it can be seen that a connection of many buildings to district heating requires detailed time planning and exact network calculations, especially of the power in the district heating network. An expansion of the district heating pipelines in the area under consideration until about 2040, where the potential limit is violated in both scenarios, is no longer necessary in the following years and thus probably uneconomical.

Network losses play an increasingly important role over time. Therefore, when the district is almost completely connected to the district heating supply, the amount of energy fed into the district heating grid exceeds the total final energy demand for heat in the area. The share of losses is lower in the calculation runs with low component quality than in scenarios with high component quality, since the losses are constant if the operating temperature of the network remains constant. In order to maintain an economic operation of the district heating network, further calculations are therefore necessary to control the current expansion of the network and to be able to assess the thermal insulation of the pipes and a possible reduction of the flow temperatures in the network. In addition, well-founded decisions can then be made as to which new areas can be sensibly connected to district heating in the future.

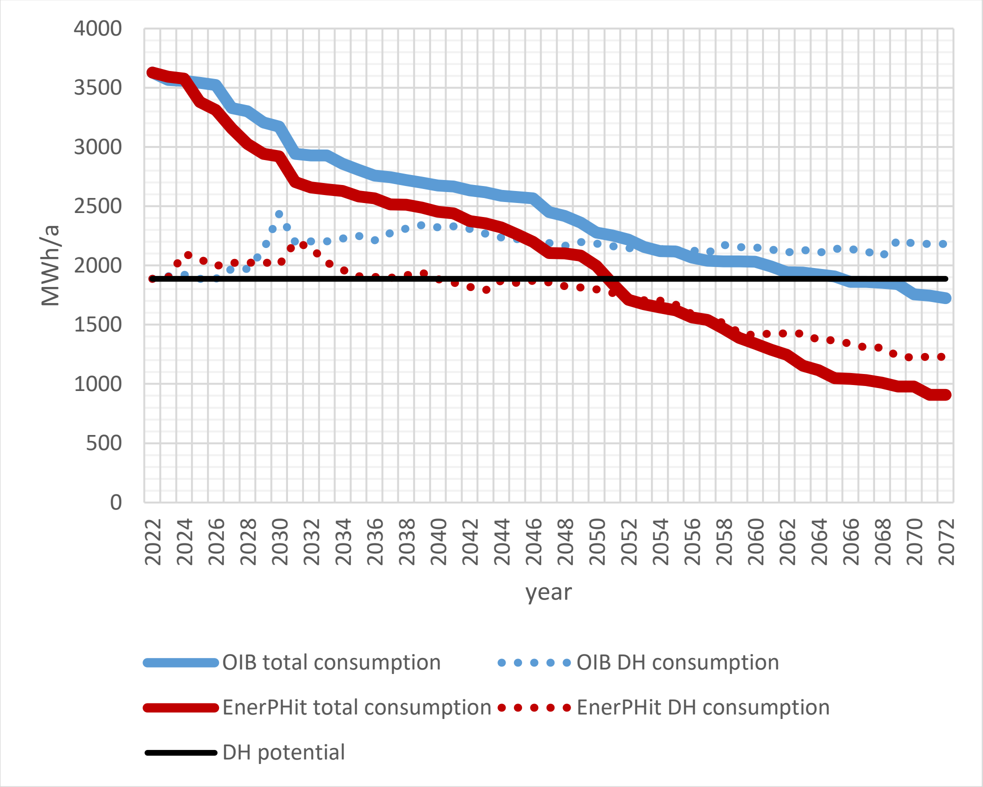
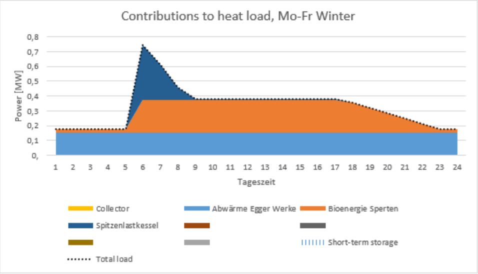


Figure 55: Total heat consumption (final energy RH+DHW) and district heating (DH) consumption (incl. network losses) compared to district heating consumption in the reference year.

The use of highly efficient building envelopes has another advantage for the operation of district heating. Figure 56 shows the power peaks in the network for the type days winter working day and summer working day. Note the different scaling of the y-axis. In the reference year, the ratio of load peaks from summer to winter on the same type day is approx. 1:10 (top), for refurbishment according to the minimum standard approx. 1:5 (middle) and for refurbishment according to EnerPHit only approx. 2:3 (bottom). Shown in this case is one example of a calculation run. This means that a high component quality enables a seasonally more even operation of the district heating network. The reason for this is the proportionally larger role of hot water consumption in the buildings, which is almost constant throughout the year, with a decreasing power demand for space heating. When using industrial waste heat, which is presumably available throughout the year, supply and demand in the district heating network match when viewed seasonally, more so for high-efficiency renovations.



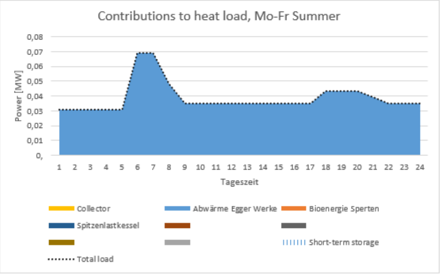


Figure 56: Load in the district heating network in the considered district on the type days winter working day and summer working day (From top to bottom: Reference year 2022, Minimum thermal envelope requirements scenario in 2072, EnerPHit renovation scenario in 2072) (Screenshot from districtPH).

The above statements were only made with regard to the quarter shown in Chapter 8. Since this district does not cover the entire supply area of the local district heating, the conclusions, especially regarding potential limits and network design, are only valid if the rest of the supply area behaves proportionally to the evaluated district. For statements on the design of the district heating network, hydraulic calculations and the exact consideration of the existing network and the distribution situation are also necessary.

3.3.7. PV POTENTIAL, EMISSION FACTORS, HEAT PUMPS

For the calculation of greenhouse gas emissions, assumptions on future electricity generation are necessary. It is assumed that by mid-century, electricity in Austria will be generated entirely from renewable sources. This is represented by a linear development from the current emission factor to an average value of renewable electricity mix. Since the resulting emission factors are very small in any case, no further distinction is made [Sinfonia 2018].

The assumption that most electricity in Austria is generated from renewable sources, especially in the second half of the period under consideration, means that electricity from the public grid is associated with low greenhouse gas emissions in the district balance sheet due to low emission factors. Against this background, the districtPH calculation shows that a conceivable, alternative scenario in which the district is supplied with decentralized heat pumps is associated with comparably low greenhouse gas emissions as the scenarios with expansion of district heating (with the same energy quality of the thermal envelope in each case).It is assumed that maintaining the existing district heating network with many connected buildings and largely renewable energy generation is economical in the case shown, if the situation in the district under consideration can be extrapolated to the entire catchment area of district heating.

Further consideration requires a detailed comparison of individual and community costs, considering the expansion of the electricity grid, biomass potential and prioritization of biomass use at the national level, and the integration of photovoltaic systems for decentralized electricity generation.

An upward potential estimation for electricity generation with photovoltaic roof systems is done with the "Web map service solar potentials Tyrol with information module". This results in a solar potential of 1828 MWh/a for the district (selection of roof areas with a potential annually yield > 950 kWh/(m2a)). [tirolsolar 2022]. For orientation, reference is made here to **a photovoltaic potential of approx. 770 MWh/a in the quarter calculated with districtPH** (standard settings for roof systems, 35 % occupancy of the available roof area). In 2072, the remaining electricity consumption from the grid can thus be reduced from approx. 380 MWh/a to approx. 190 MWh/a in both scenarios. Annual balancing results in a potentially significantly greater electricity production by rooftop photovoltaic systems than is consumed in the district (net zero).

In principle, the installation of rooftop photovoltaic systems in the neighborhood under consideration is urgently desirable, at least to cover self-consumption. A differentiation on the basis of greenhouse gas emissions is again not possible with the prerequisite of renewable electricity generation in the public power grid. The advantages of decentralized generation and the inclusion of other consumers (e.g. electromobility) must be weighed up separately.

3.3.8. GREENHOUSEGAS EMISSIONS

Figure 57 shows the greenhouse gas emissions of the district over time. In both scenarios, a significant reduction is possible, especially due to demolition and new construction with passive house quality. As a consequence, the longer lifetime of the peak load boiler in the minimum thermal envelope scenario, as well as the remaining decentralized heat generators in the buildings, causes a difference of more than 100 % GHG emissions compared to the scenario with high-efficiency renovations in 2072.

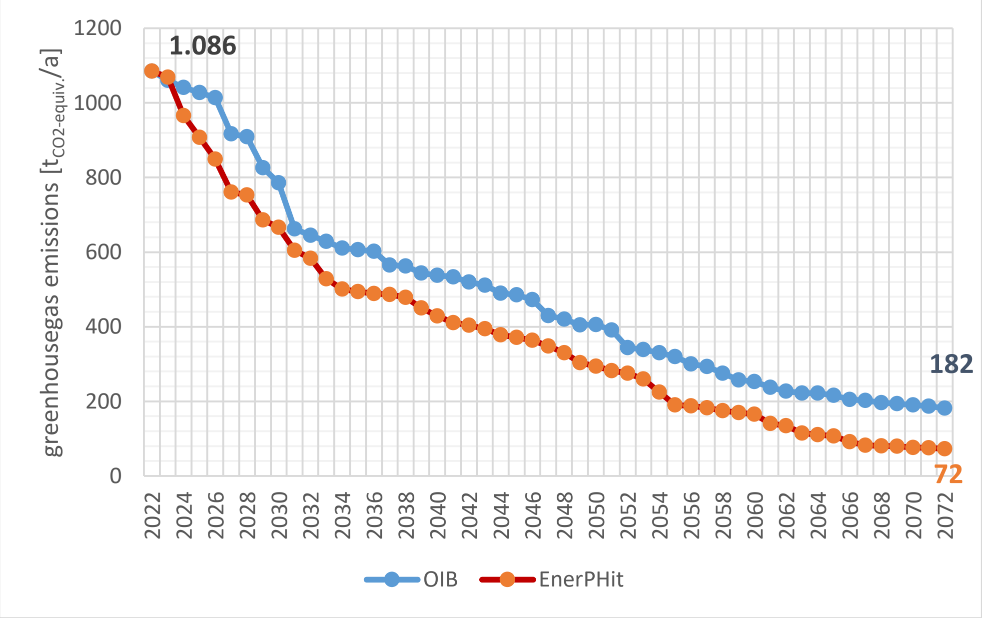


Figure 57: Greenhouse gas emissions over time with thermal envelope to minimum standard compared to EnerPHit refurbishment in $t_{CO2-equivalent}$/a. (Own representation)

4. BULGARIA

4.1. SUMMARY

In this study, a building district in Golo Bardo in Gabrovo, Bulgaria with currently a total of 23 buildings and a total treated floor area of 103 606 m² was investigated by the use of the districtPH tool. Different scenarios for its development until the year 2072 were explored.

The focus was on the comparing the energy savings from two renovation approaches – on one hand, renovation up to the National Standards, and on the other building renovation up to EnerPHit standard and lastly a scenario where the buildings were renovated up to EnerPHit standard with photovoltaic panels installed on most roofs, in addition to a solar power plant placed in an adjacent area of the district. The district doesn't have district heating and such is not envisioned by the municipality thus the calculations for heat supply from district heating have been neglected.

In addition, an estimation of the PV potential on the roof surfaces of the investigated district was also carried out. The development of future GHG emissions was estimated for the three different renovation scenarios. However, due to the very limited area under consideration in this study, these results are only theoretical and subject to great number of variables, but they do demonstrate the far-reaching opportunities and advantages of comprehensive high-efficiency EnerPHit refurbishment.

4.2. PRESENT STATE OF THE DISTRICT

The selected district presents a good sample for a typical neighbourhood in Bulgaria. It consists of a number of large multi-family residential buildings, a school, a kindergarten, and several shops.

A very small number of the buildings were built after year 2000 and the rest were built during socialist times between years 1970 and 1980. All the residential building were build using the large panel system-building method (LPS or Plattenbauten).

Four out of all sixteen multi-family buildings in the district were renovated under the National Energy Efficiency Programme in Bulgaria. The rest of the buildings have not been fully renovated, however there are individual homeowners that have implemented some energy efficiency measures, often these refer only to external facades insulation or change of windows. Furthermore, the school and the kindergarten in the district have been renovated. Until very recently, the multi-family buildings used solid fuels as heating source, but at the moment most of the apartments in the neighbourhood are heated by electricity. Currently, there are no renewable energy sources used in the district.

Scenarios for the development of the electricity demand are developed and presented in dependence of the renovation depth. In addition, the potential of existing renewable energy sources is analysed.

4.2.1. LOCATION AND SURROUNDINGS

Gabrovo is a town in central Bulgaria situated along the Yantra River in the northern foothills of the Shipchen Lobe of the Balkan Mountains. The selected area for investigation is part of the Golo Bardo district in Gabrovo. It is located west of the Yantra River, between the districts of Varovnik to the south, Padalo to the east and Mladost to the north. It has an altitude of about 425 meters above sea level (see Figure 61). The region has a varied semi-mountainous and mountainous topography and temperate continental climate, characterised by cold winters and relatively warm summers. Precipitation is of a markedly continental character. The region is also characterised by high annual sunshine duration. Average annual temperatures are around 10 °C. [Gabrovo 2021]

Figure 58: Surrounding and shading situation of Golo Bardo district in Gabrovo.

The selected area of the Golo Bardo district is a community of about 3250 inhabitants in a city environment. The location of the district is shown in Figure 62. It contains mainly multi-family buildings built between 1970-1980.

Figure 59: City of Gabrovo and the evaluated district Golo Bardo.

4.2.2. CLIMATE DATA SET

The used climate data set for Gabrovo was obtained through simulation and a combination of different sources like: Meteonorm, National Institute of Meteorology and Hydrology and was validated from Passive House Institute GmbH.

Further details of the climate data set can be observed on the figures below:

Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating load		Cooling load		PER factors
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Weather 1	Weather 2	
Winter days	31	28	31	12	0	0	0	0	0	11	30	31					
Summer days	0	0	0	18	31	30	31	31	30	20	0	0					
Gabrovo, Bulgaria	Latitude:	42,5	Longitude °	25,2	Altitude m	400	Daily Temperature Swing Summer (K)			11,2	Radiation Data:	kWh/(m²month)	Radiation: W/m²		Radiation: W/m²		
Exterior temperature	-0,1	1,4	5,8	12,8	17,5	21,2	23,7	23,1	19,2	12,9	6,3	0,5	-2,7	2,2	27,1	27,1	1,30
Radiation North	23	34	49	60	75	81	80	74	58	39	25	20	20	5	100	100	1,30
Radiation East	41	55	74	77	102	112	114	118	94	64	42	35	30	5	170	170	1,80
Radiation South	73	87	96	72	84	88	93	115	116	96	72	64	70	10	180	180	1,10
Radiation West	41	55	74	77	102	112	114	118	94	64	42	35	30	5	170	170	1,15
Horizontal radiation	51	77	117	135	183	199	205	207	152	92	54	42	45	10	340	340	
Dew point temperature	-3,1	-3,3	-1,2	3,5	9,6	12,1	13,6	13,7	11,0	7,4	3,1	-0,1			16,7	16,7	
Sky temperature	-21,6	-19,8	-14,4	-5,3	1,1	6,4	10,0	9,1	3,5	-5,2	-13,8	-20,9			18,6	16,7	

	Data for heating Annual method	Data from monthly balance Heating	Cooling	
Heating / cooling period	175	151	245	d/a
Heating / cooling degree hours	69	62	-51	kKh/a
Radiation North	179	150	517	kWh/(m²a)
Radiation East	287	246	754	kWh/(m²a)
Radiation South	442	392	761	kWh/(m²a)
Radiation West	287	246	754	kWh/(m²a)
Horizontal radiation	407	340	1289	kWh/(m²a)

Heating period from day no. 293

to day no. 102

Ground albedo 0,1

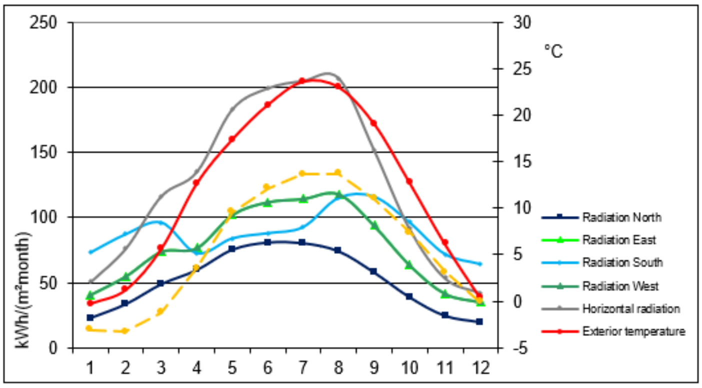


Figure 60: Climate data for the city of Gabrovo.

4.2.3. BUILDING STOCK

The choice of the area under consideration is depicted in Figure 4964.

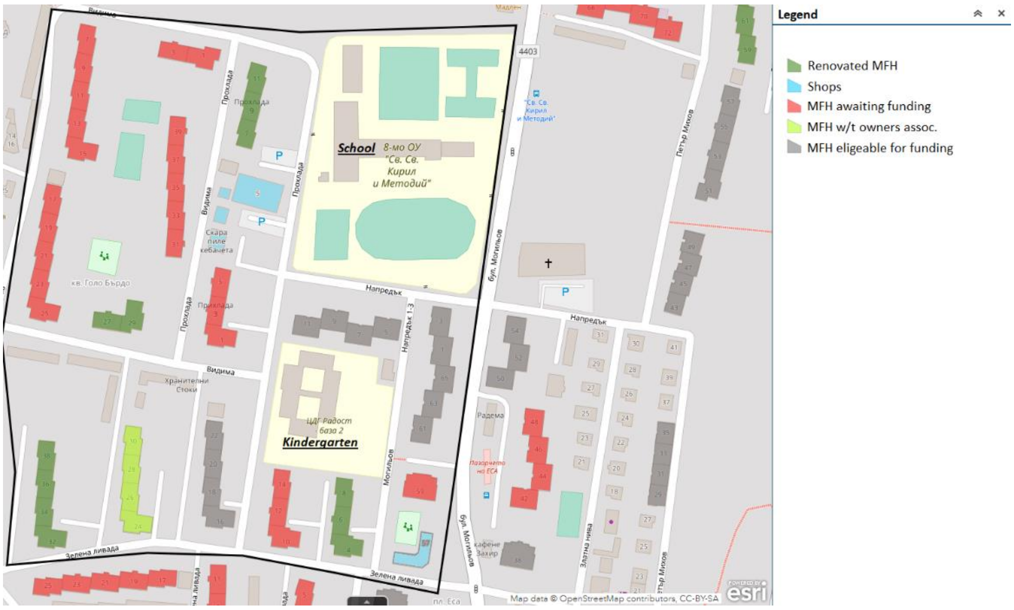


Figure 61: Evaluated district and building types in the area.

The district area comprises of a total of 23 buildings. Sixteen of them are multi-family buildings but there is also a school, a kindergarten, a supermarket and several smaller shops and a mixed-use building in the area under consideration.

All buildings of the Golo Bardo district were considered as individual buildings in districtPH according to the available building data (thermal envelope, heating, and domestic hot water use (DHW)). Four of the multi-family buildings are sub optimally renovated without achieving the full EE potential through the National Programme for Energy Efficiency in Multi-family Buildings.

As most of the buildings in the area were built around the same time using the same building technology and similar floor plans, the data from the building passports (energy audit and technical audit) of the 4 renovated buildings was used for calculating the building data (U-values for walls, windows, floors, and roofs) for the other multi-family buildings. The gross floor area is measured based on the building exterior dimensions on the map, and the number of full stories is determined based on the national building cadastre.

The school and the kindergarten are renovated and in the districtPH they were assigned a custom building type according to their available energy audits. The other buildings in the neighbourhood e.g., the supermarket and the other small retail buildings were assigned a custom building type according to the national reference values for this type of buildings.

For the age of all buildings, data from the national cadaster was used, indicating that all the 16 multi-family buildings and the kindergarten were built in the period between 1975 and 1980 during the socialist regime in the country at the time. The treated floor area is determined in the same way as described above.

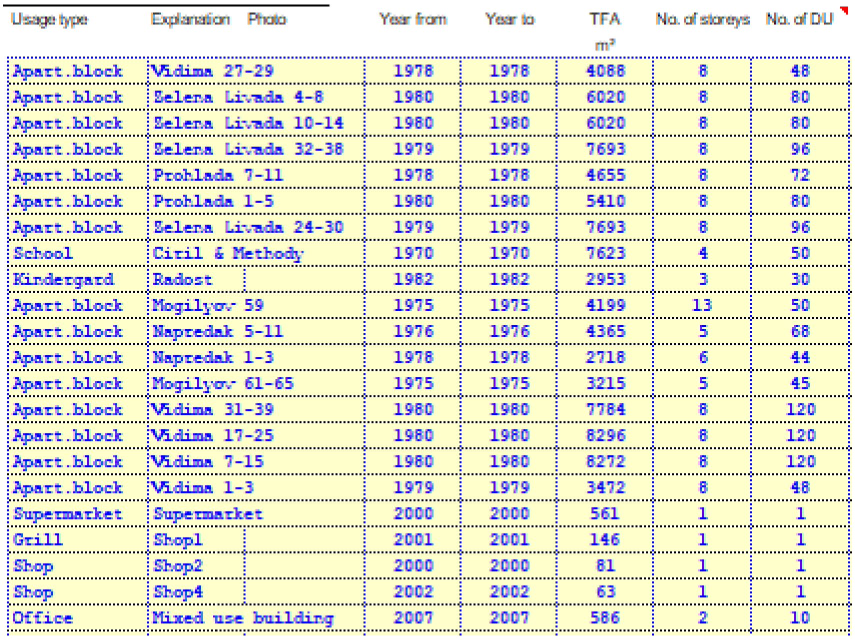
The districtPH software was provided with comprehensive data on the layout and positioning of the entire district.

- Total Treated Floor Area = 103 606 m^2

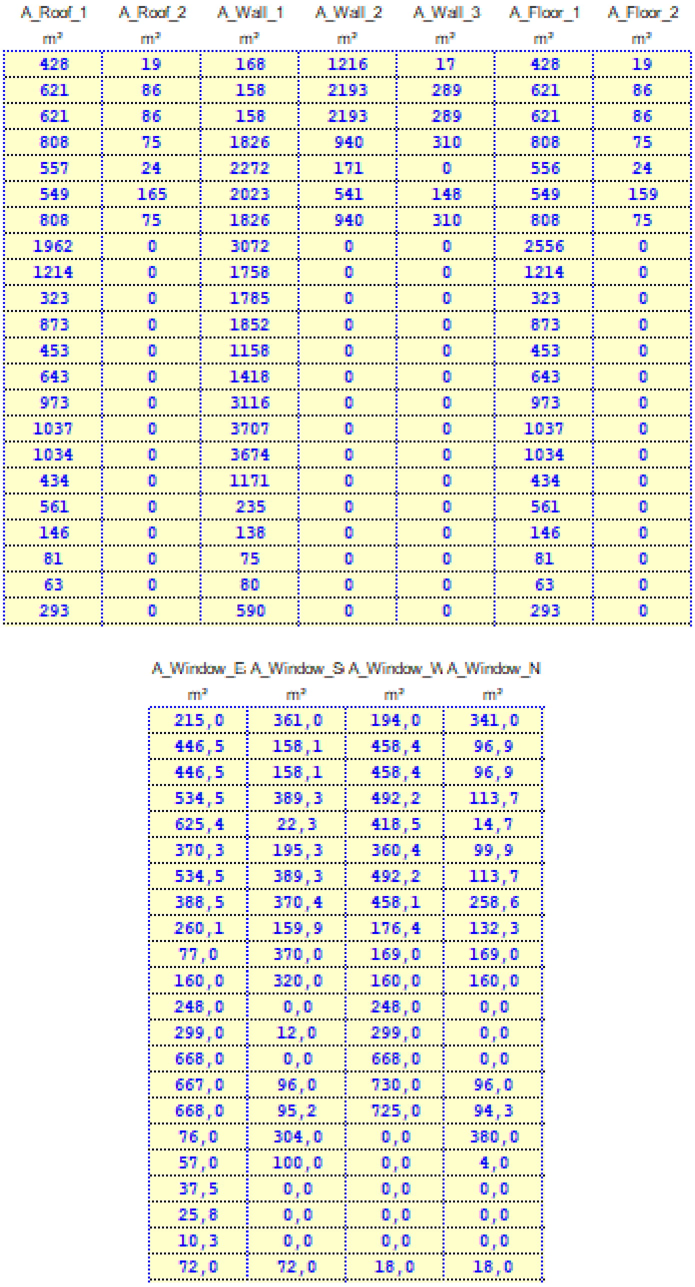
- Total No. of storeys = 138
- No. of dwelling units = 1357
- Roof Area = 15 895 m^2
- Wall Area = 44 893 m^2
- Floor Area = 16 480 m^2
- East Windows Area = 7 421 m^2
- South Windows Area = 3 962 m^2
- West Windows Area = 7 018 m^2
- North Windows Area = 2 303 m^2

All areas are in contact with outdoor air except the floor area which is in contact with an unheated basement. There are two different types of building assemblies for the roof and three different types for the wall.

The entered buildings parameters are as follows:



Usage type	Explanation	Photo	Year from	Year to	TFA m^2	No. of storeys	No. of DU
Apart.block	Vidima 27-29		1978	1978	4088	8	48
Apart.block	Selena Livada 4-8		1980	1980	6020	8	80
Apart.block	Selena Livada 10-14		1980	1980	6020	8	80
Apart.block	Selena Livada 32-38		1979	1979	7693	8	96
Apart.block	Prohlada 7-11		1978	1978	4655	8	72
Apart.block	Prohlada 1-5		1980	1980	5410	8	80
Apart.block	Selena Livada 24-30		1979	1979	7693	8	96
School	Ciril & Methody		1970	1970	7623	4	50
Kindergard	Radost		1982	1982	2953	3	30
Apart.block	Mogilyov 59		1975	1975	4199	13	50
Apart.block	Napredak 5-11		1976	1976	4365	5	68
Apart.block	Napredak 1-3		1978	1978	2718	6	44
Apart.block	Mogilyov 61-65		1975	1975	3215	5	45
Apart.block	Vidima 31-39		1980	1980	7784	8	120
Apart.block	Vidima 17-25		1980	1980	8296	8	120
Apart.block	Vidima 7-15		1980	1980	8272	8	120
Apart.block	Vidima 1-3		1979	1979	3472	8	48
Supermarket	Supermarket		2000	2000	561	1	1
Grill	Shop1		2001	2001	146	1	1
Shop	Shop2		2000	2000	81	1	1
Shop	Shop4		2002	2002	63	1	1
Office	Mixed use building		2007	2007	586	2	10



A_Roof_1	A_Roof_2	A_Wall_1	A_Wall_2	A_Wall_3	A_Floor_1	A_Floor_2
m²	m²	m²	m²	m²	m²	m²
428	19	168	1216	17	428	19
621	86	158	2193	289	621	86
621	86	158	2193	289	621	86
808	75	1826	940	310	808	75
557	24	2272	171	0	556	24
549	165	2023	541	148	549	159
808	75	1826	940	310	808	75
1962	0	3072	0	0	2556	0
1214	0	1758	0	0	1214	0
323	0	1785	0	0	323	0
873	0	1852	0	0	873	0
453	0	1158	0	0	453	0
643	0	1418	0	0	643	0
973	0	3116	0	0	973	0
1037	0	3707	0	0	1037	0
1034	0	3674	0	0	1034	0
434	0	1171	0	0	434	0
561	0	235	0	0	561	0
146	0	138	0	0	146	0
81	0	75	0	0	81	0
63	0	80	0	0	63	0
293	0	590	0	0	293	0

A_Window_E	A_Window_S	A_Window_W	A_Window_N
m²	m²	m²	m²
215,0	361,0	194,0	341,0
446,5	158,1	458,4	96,9
446,5	158,1	458,4	96,9
534,5	389,3	492,2	113,7
625,4	22,3	418,5	14,7
370,3	195,3	360,4	99,9
534,5	389,3	492,2	113,7
388,5	370,4	458,1	258,6
260,1	159,9	176,4	132,3
77,0	370,0	169,0	169,0
160,0	320,0	160,0	160,0
248,0	0,0	248,0	0,0
299,0	12,0	299,0	0,0
668,0	0,0	668,0	0,0
667,0	96,0	730,0	96,0
668,0	95,2	725,0	94,3
76,0	304,0	0,0	380,0
57,0	100,0	0,0	4,0
37,5	0,0	0,0	0,0
25,8	0,0	0,0	0,0
10,3	0,0	0,0	0,0
72,0	72,0	18,0	18,0

Figure 62: Typology worksheet inputs. (Screenshot from districtPH)

4.2.4. BUILDING ELEMENTS

The thermal envelope of most of the existing buildings is totally uninsulated for the majority of the district's buildings. The average aggregated U-Values for the walls, the floors, the roofs and the windows are as follows:

- U-Wall = 1,26 W/m²K
- U-Floor = 0,83 W/m²K
- U-Roof = 0,86 W/m²K
- U-Window = 2,01 W/m²K
- g-Window = 0,50

The heat losses through the envelope are crucial in a city like Gabrovo, with cold winters, the heating demand is high.

4.2.5. THERMAL BRIDGES

There are two types of thermal bridges: Geometric and Structural

Geometric thermal bridges are caused by geometrical disconnection of a building element. Constructional thermal bridges are caused by material discontinuity of a building element.

In all investigated buildings in the district both types of thermal bridges are present. Calculations of the most important thermal bridges of each building, show an average result of 0,15 W/m^{2}K heat losses due to thermal bridges. This value was used in the calculations.

4.2.6. AIRTIGHTNESS

In older and uninsulated buildings, air leakage through the building's outer layer is significant and contributes to a substantial amount of heat loss, which cannot be overlooked. Although it is not practical to conduct a pressurization test on every building, data from existing energy audits of building in the district was used to determine input values. Based on the gathered data, the n50 value for renovated buildings is taken as 1,5 air changes per hour, and for the non-renovated buildings in the district the n50 value is taken as 3 air changes per hour.

4.2.7. DISTRICT HEATING

Currently, in the city of Gabrovo there is one central district heating plant, the “Gabrovo Heating Company” which is a sole owner joint stock company. Unfortunately, the local district heating network is not connected to the examined district of Golo Bardo, thus none of the multifamily buildings use central heating for heating or DHW purposes or have any kind of centralized heat supply systems installed. Although generally the use of district heating is associated with larger carbon reductions, reduced maintenance costs, improved comfort and air quality, the city of Gabrovo has a long and painful experience with the local district heating company. One such example was in 2017 when Gabrovo Municipality filed a lawsuit against the district heating company, which was subsequently joined by educational institutions, cultural institutions, and citizens. The claim was for systematic provision of poor-quality service in violation of the Energy Act. And in November 2019 it was decided by the Veliko Tarnovo Administrative Court, which upheld the decision of the Gabrovo District Court, which ordered the district heating company to pay penalties to its subscribers for the material and non-material damage caused. Data shows that for heating season 2017-2018, the company's clients were a of total 4409, including 4296 domestic and 133 commercial, which represents less than a quarter of the buildings in Gabrovo and currently the number is potentially even lower as many homeowners have decided to switch to other heating sources. Due to the low-quality service the local homeowners are extremely reserved to the possibility to heat their homes centrally and deal with the district heating company. Thus, for the purposes of this report no possible future connection to the district heating network is envisioned or explored here.

4.2.8. ELECTRICITY AND GAS

According to the information provided by the municipal experts, in the neighbourhood under consideration, nearly all heat demand is covered by heat generators installed in apartments.

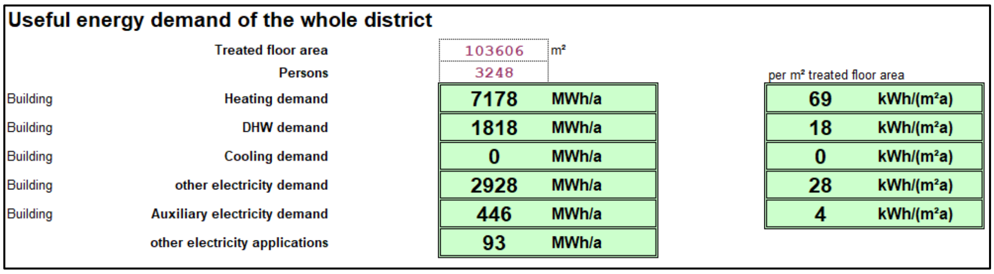
For individual apartments these are air conditioning units, wood stoves, pellet boilers and **gas boilers for the school and kindergarten**. It can be safely assumed that some of the apartments in the buildings are not inhabited and do not have heating or cooling units installed, which means that they operate without any temperature control i.e., in free floating conditions. Furthermore, there are no solar thermal systems installed in the buildings to meet the demand for hot water. The efficiency level of the other electric devices is set at 5, which means that they were installed between 2000 and 2010 on average.

4.2.9. COOLING PERIOD AND DEMAND

After analysing all gathered building information and data from existing energy audits, it has been found that most of the apartments have air conditioning systems installed. However, there does not appear to be any noticeable increase in energy consumption during the summer months when these systems are likely being used most frequently. It can therefore be assumed that the operation of these air conditioning systems does not significantly impact the overall energy consumption of the building. It is also important to note that the mild summers of the region where the buildings are located play a significant role in the cooling of the apartments during the summer months. It is assumed that during most of the summer season natural ventilation provides enough cooling to keep the apartments comfortable without relying solely on-air conditioning.

4.2.10. HEATING PERIOD AND DEMAND

According to the provided climate data for the region the heating period begins on 20 October 2021 and continues to 12 April 2022 equating to a total of 175 days with a need for heating. The total **heating demand** for the evaluated district is **7178 MWh/a.** This corresponds to **69 kWh/m^{2}a.** In addition to this are the heat demand for domestic hot water **(1818 MWh/a)** and the total other electricity demand **(3466 MWh/a)** according to Figure 5066.



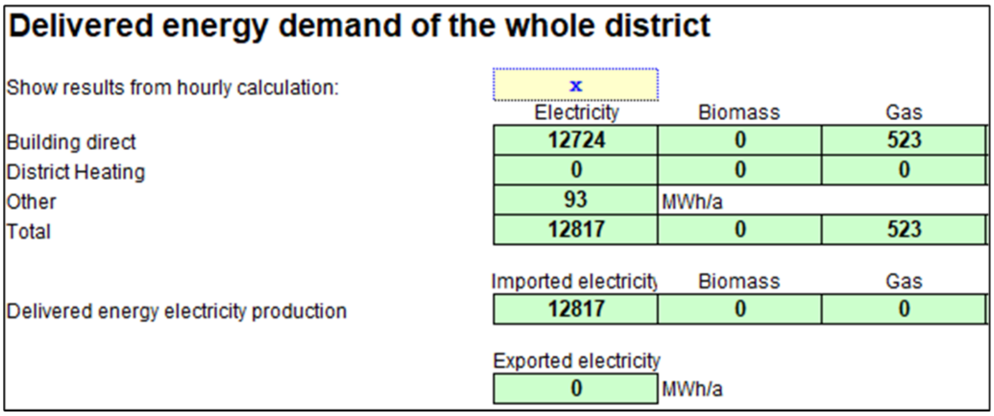
Useful energy demand of the whole district

	Treated floor area	103606	m²		
	Persons	3248		per m² treated floor area	
Building	Heating demand	7178	MWh/a	69	kWh/(m²a)
Building	DHW demand	1818	MWh/a	18	kWh/(m²a)
Building	Cooling demand	0	MWh/a	0	kWh/(m²a)
Building	other electricity demand	2928	MWh/a	28	kWh/(m²a)
Building	Auxiliary electricity demand	446	MWh/a	4	kWh/(m²a)
	other electricity applications	93	MWh/a		

Figure 63: Summary of the calculation results of the reference year 2022. (Screenshot from districtPH)

4.2.11. HEAT GENERATION

The final energy demand of the district in 2022 by energy source is shown in Figure 5267. It includes the amount of electricity consumed. Based on gathered data, it is concluded that the photovoltaic power generation in the district is non-existent in the reference year.



Delivered energy demand of the whole district

Show results from hourly calculation: x

	Electricity	Biomass	Gas
Building direct	12724	0	523
District Heating	0	0	0
Other	93	MWh/a	
Total	12817	0	523

	Imported electricity	Biomass	Gas
Delivered energy electricity production	12817	0	0

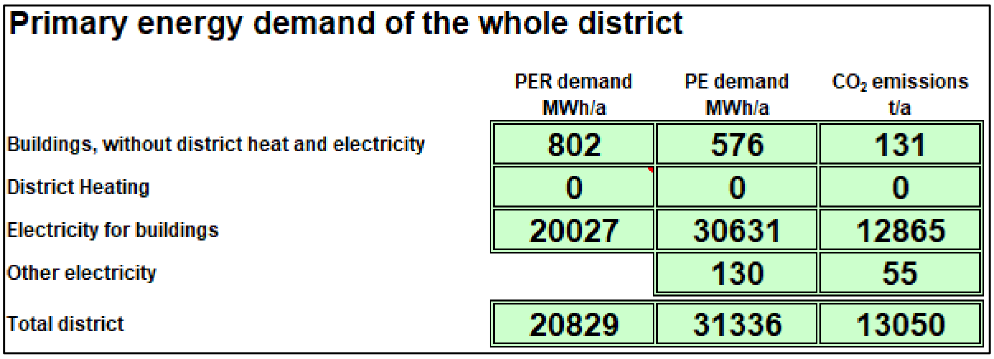
Exported electricity

0 MWh/a

Figure 64: Final energy demand in the reference year 2022. (Screenshot from districtPH)

4.2.12. GREENHOUSE GAS EMISSIONS (GHG)

For the district under consideration, this results in greenhouse gas emissions of **13050 t CO_2 equivalent** in the reference year, shown in the Figure 68.



Primary energy demand of the whole district

	PER demand MWh/a	PE demand MWh/a	CO_2 emissions t/a
Buildings, without district heat and electricity	802	576	131
District Heating	0	0	0
Electricity for buildings	20027	30631	12865
Other electricity		130	55
Total district	20829	31336	13050

Figure 65: Primary energy demand and CO_2 emissions in the reference year 2022. (Screenshot from districtPH)

4.2.13. PUBLIC ELECTRICITY CONSUMERS

The public electricity consumers in the district, including street lighting and electric vehicles, play an important role in the overall energy demand and emissions of the district. The street lighting for the 3248 residents is estimated to have approximately 200 light points with an installed lighting capacity of 16 kW and an average capacity per lamp of 80 W. This represents a significant energy demand for the street lighting, which could potentially be reduced through the use of more energy-efficient lighting technologies such as LED lighting. With regards to electric individual transport, the estimated 0,6 vehicles per inhabitant and the annual kilometres travelled per vehicle of 10 000 km/year, results in a significant contribution to the district's overall energy demand and emissions. The fraction of electric vehicles in the district is still very low at 1%, indicating that there is significant potential for growth in the adoption of electric vehicles in the district. Encouraging the use of electric vehicles through incentives and infrastructure development, such as charging stations, can help to further reduce the district's reliance on fossil fuels and improve its overall sustainability.

4.3. REFURBISHEMENT SCENARIOS

The whole district will be refurbished in **a period of about 10-15 years** following a holistic approach. Below are the explanations for the presumptions concerning the factors that affect the time-related progression of the considered target variables in the district.

4.3.1. CALCULATION MODEL

To accurately calculate multiple scenarios over several decades, a fast and precise method was necessary. This method needed to determine the portion of total heat load covered by each heat generator and account for short and long-term storage. An hourly analysis was implemented to allow for detailed investigations and comparison with simplified methods but kept separate from the rest of the calculation model for easy removal. While this model may have long calculation times for long-term scenarios, it is useful for detailed investigations of a specific district state. The hourly analysis accounts for the fluctuating nature of renewable energy sources and distinguishes between Monday to Friday, Saturday, and Sunday for load distribution. However, this approach may be less accurate during extremely cold or hot periods, mild spring or autumn days, or around holidays. Despite this, comparisons with hourly calculations resulted in an acceptable agreement.

4.3.2. CALCULATION PERIOD

The period of 50 years is chosen as the highest achievable duration to be analysed in districtPH. As the computations are dependent on probabilities, the outcomes are presented as an average of 10 simulations (Monte Carlo simulation) unless specified otherwise.

4.3.3. LIVING AREA AND REDENSIFICATION

In the district under consideration, no buildings have been demolished and no new buildings are expected to be constructed. The treated floor area in the district remains the same until the end of the period under consideration in 2072. However, this is the current situation and could be subject to change in the future depending on the municipal urban development plan.

4.3.4. COMPONENT LIFETIME

The time for replacement of a component or system becomes most probable at the end of its component life. The calculation is done according to districtPH logic using probabilities. For this purpose, the following component lifetimes are assumed in districtPH.

Component	Average lifetime
Wall	50 years
Floor	40 years
Roof	40 years
Window	30 years
Entrance door	30 years
Airtightness	40 years
Technical building equipment (Heating, DHW, Cooling)	30 years

Table 3: Average lifetime of building components (own estimate based on BBSR 2017 and BTE 2008)

4.3.5. COMPONENT QUALITY

The quality of the building envelope after refurbishment is crucial for reducing the energy demand in the district. Two scenarios are developed for this purpose.

For refurbishment according to National minimum requirements, it is assumed that the thermal transmittance values of the building components correspond to the minimum standard according to the National Methodology for Calculation of Energy Performance published by the Ministry of Regional Development and Public Works on the 18th of November 2022.

In contrast, the second refurbishment scenario investigates the renovation of the buildings in the district up to the Passive House standard for refurbishment i.e. the EnerPhit standard.

Furthermore, a third renovation scenario was developed. It examines the renovation of all buildings in the district up to EnerPHit standard with the additional installation of photovoltaic solar panels on the roofs of the buildings and the installation of a photovoltaic solar park near the district under consideration.

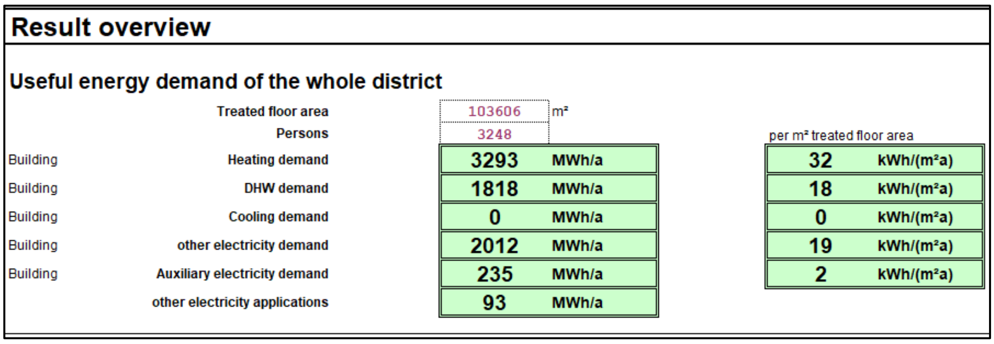
The component qualities shown indicate the most probable standard after refurbishment. In each case, a standard deviation of one quality step around the most probable standard is assumed according to districtPH calculation logic.

Component:	**Reference quality Minimum standard** (room set temperature for heating >15°C)	**Quality according to Passive House Standard for refurbishment (EnerPHit)**
Wall	$U = 0{,}26\ W/(m^2*K)$	$U = 0{,}15\ W/(m^2*K)$
Floor	$U = 0{,}25\ W/(m^2*K)$	$U = 0{,}15\ W/(m^2*K)$
Roof	$U = 0{,}25\ W/(m^2*K)$	$U = 0{,}15\ W/(m^2*K)$
Window	$U = 1{,}4\ W/(m^2*K)$	$U = 0{,}85\ W/(m^2*K)$
Entrance door	$U = 2{,}0\ W/(m^2*K)$	$U = 1{,}10\ W/(m^2*K)$
Airtightness	N/A	$n_{50} = 0{,}6\ h^{-1}$

Table 4: Component quality after refurbishment (Based on [Ordinance №RD-02-20-03] and [PHI 2020])

4.4. REFURBISHEMENT UP TO NATIONAL STADARDS

The simulation was carried out for the whole neighbourhood taking into consideration all the minimum standard component parameters mentioned in Table 4. The calculation model is set up in such a way that a refurbishment is possible evert year. In addition, taking into account the specific country and market conditions, a renovation rate of 10% for the buildings in the district is selected as this is assumed to be the most probable and feasible renovation rate. The results of the useful energy demand of the district after the refurbishment is shown in the figure below:



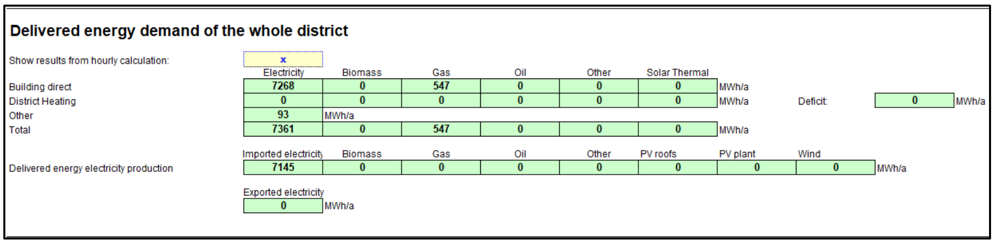
Result overview

Useful energy demand of the whole district

	Treated floor area	103606	m²		
	Persons	3248		per m² treated floor area	
Building	Heating demand	3293	MWh/a	32	kWh/(m²a)
Building	DHW demand	1818	MWh/a	18	kWh/(m²a)
Building	Cooling demand	0	MWh/a	0	kWh/(m²a)
Building	other electricity demand	2012	MWh/a	19	kWh/(m²a)
Building	Auxiliary electricity demand	235	MWh/a	2	kWh/(m²a)
	other electricity applications	93	MWh/a		

Figure 66: Useful energy demand of the whole district in the year 2072. (Screenshot from districtPH)

The amount of delivered energy that is required to meet the energy needs of the entire district during the year 2072 is summarised below in Figure 70.



Delivered energy demand of the whole district

Show results from hourly calculation: x

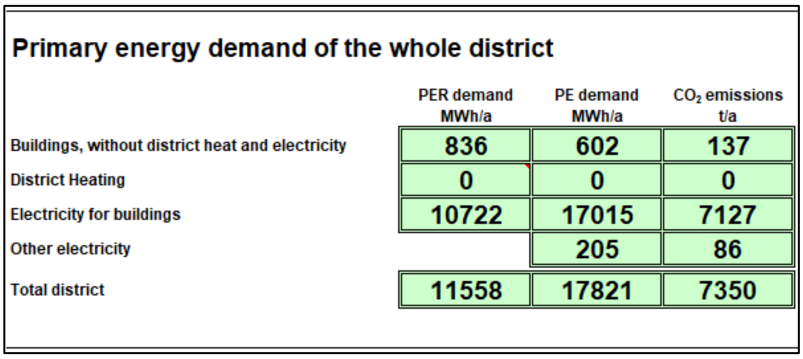
	Electricity	Biomass	Gas	Oil	Other	Solar Thermal			
Building direct	7268	0	547	0	0	0	MWh/a		
District Heating	0	0	0	0	0	0	MWh/a	Deficit:	0 MWh/a
Other	93	MWh/a							
Total	7361	0	547	0	0	0	MWh/a		

	Imported electricity	Biomass	Gas	Oil	Other	PV roofs	PV plant	Wind	
Delivered energy electricity production	7145	0	0	0	0	0	0	0	MWh/a

Exported electricity: 0 MWh/a

Figure 67: Delivered energy demand of the whole district in the year 2072. (Screenshot from districtPH)

Figure 71 shows the amount of primary energy that will be required to meet the energy needs of the district during the year 2072, as well as the amount of carbon dioxide (CO_2) emissions that will result from the consumption of that energy.



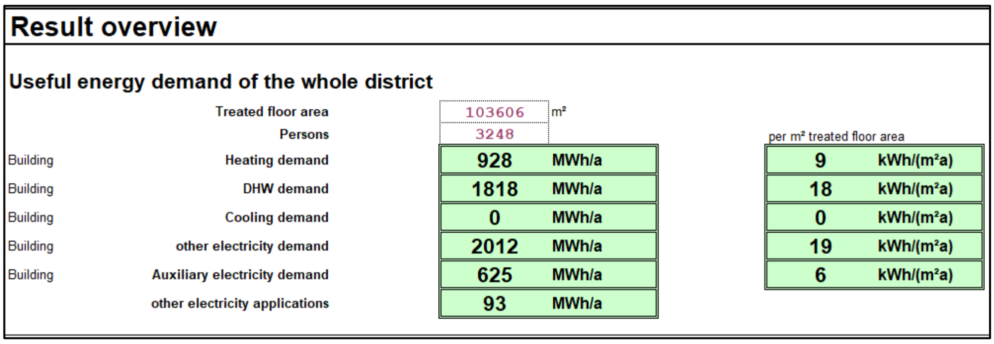
Primary energy demand of the whole district

	PER demand MWh/a	PE demand MWh/a	CO_2 emissions t/a
Buildings, without district heat and electricity	836	602	137
District Heating	0	0	0
Electricity for buildings	10722	17015	7127
Other electricity		205	86
Total district	11558	17821	7350

Figure 68: Primary energy demand and CO_2 emissions in the year 2072. (Screenshot from districtPH)

4.5. REFURBISHEMENT UP TO ENERPHIT STANDARDS

The simulation was carried out for the whole neighbourhood taking into consideration all the minimum standard component parameters mentioned in Table 4. The calculation model is set up in such a way that a refurbishment is possible evert year. In addition, taking into account the specific country and market conditions, a renovation rate of 10% for the buildings in the district is selected as this is assumed to be the most probable and feasible renovation rate. Furthermore, for each apartment a ventilation unit with 80% heat recovery is envisioned to be installed. The results of the energy demand of the district after the refurbishment is shown in the figure below:



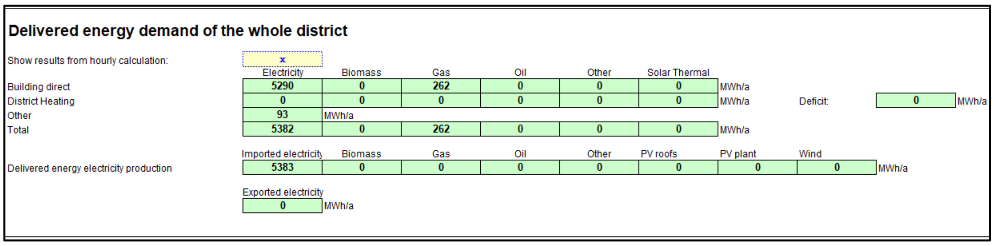
Result overview

Useful energy demand of the whole district

				per m² treated floor area	
	Treated floor area	103606	m²		
	Persons	3248			
Building	Heating demand	928	MWh/a	9	kWh/(m²a)
Building	DHW demand	1818	MWh/a	18	kWh/(m²a)
Building	Cooling demand	0	MWh/a	0	kWh/(m²a)
Building	other electricity demand	2012	MWh/a	19	kWh/(m²a)
Building	Auxiliary electricity demand	625	MWh/a	6	kWh/(m²a)
	other electricity applications	93	MWh/a		

Figure 69: useful energy demand of the whole district in the year 2072. (Screenshot from districtPH)

The amount of delivered energy that is required to meet the energy needs of the entire district during the year 2072 is summarised below in Figure 73.



Delivered energy demand of the whole district

Show results from hourly calculation: x

	Electricity	Biomass	Gas	Oil	Other	Solar Thermal	
Building direct	5290	0	262	0	0	0	MWh/a
District Heating	0	0	0	0	0	0	MWh/a
Other	93	MWh/a					
Total	5382	0	262	0	0	0	MWh/a

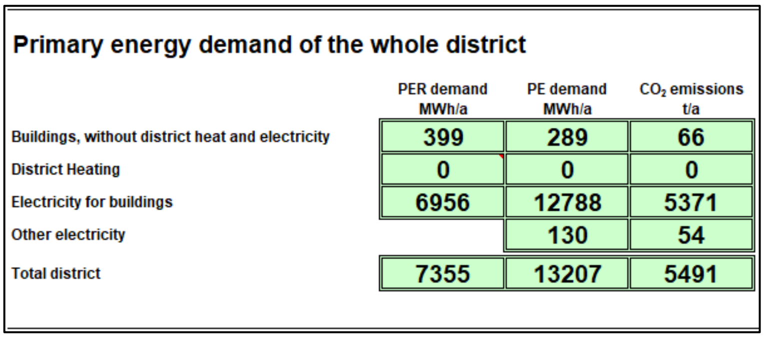
Deficit: 0 MWh/a

	Imported electricity	Biomass	Gas	Oil	Other	PV roofs	PV plant	Wind	
Delivered energy electricity production	5383	0	0	0	0	0	0	0	MWh/a

Exported electricity: 0 MWh/a

Figure 70: Delivered energy demand of the whole district in the year 2072. (Screenshot from districtPH)

Figure 74 shows the amount of primary energy that will be required to meet the energy needs of the district during the year 2072, as well as the amount of carbon dioxide (CO_2) emissions that will result from the consumption of that energy.



Primary energy demand of the whole district

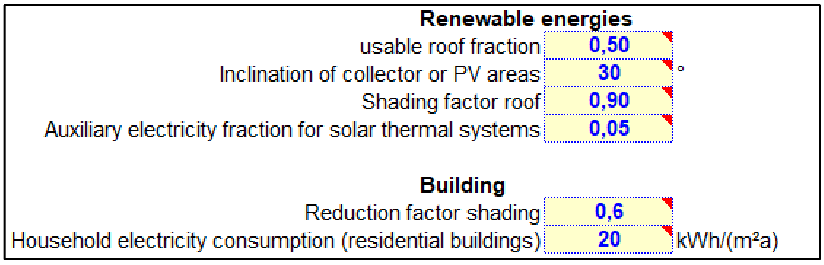
	PER demand MWh/a	PE demand MWh/a	CO_2 emissions t/a
Buildings, without district heat and electricity	399	289	66
District Heating	0	0	0
Electricity for buildings	6956	12788	5371
Other electricity		130	54
Total district	7355	13207	5491

Figure 71: Primary energy demand and CO_2 emissions in the year 2072. (Screenshot from districtPH)

4.6. REFURBISHEMENT UP TO ENERPHIT STADARDS WITH PV MODULES

The Gabrovo region is in a good geographical location for the installation of roof PV modules and the construction of photovoltaic plant because the region is at a relatively high altitude, which results in less air dust and lower average annual temperatures. In addition, the following advantages have been identified in a study done by experts: the global daily horizontal radiation is about 88 %, the hours of sunshine are about 2600 hours per year, the main share of diffuse radiation is about 65%, which is determined by the fogs in the area, the proportion of sunny days in Gabrovo is about 40-50%, and additionally because the theoretical amounts of solar radiation are as follows: the amount of daily global horizontal radiation is 3500 Wh/m^2 and the amount of direct normal radiation is 4000 Wh/m^2. Taking all these factors into account, this report investigates the potential installation of PV modules on the roofs of buildings and also the construction of a solar power plant in an adjacent land plot owned by the municipality of Gabrovo [Kostadinov 2011].

For the calculation model of this renovation scenario the following input parameters were selected for the installation of PV modules on the roofs of the buildings:



Renewable energies

usable roof fraction	0,50	
Inclination of collector or PV areas	30	°
Shading factor roof	0,90	
Auxiliary electricity fraction for solar thermal systems	0,05	

Building

Reduction factor shading	0,6	
Household electricity consumption (residential buildings)	20	kWh/(m²a)

Figure 72: Set-up parameters regarding PV modules installation. (Screenshot from districtPH)

The selected PV modules are Monocrystalline solar panels with nominal power of 235 Wp and single module area of 1,6 m^2. All modules are oriented 180 degrees deviation from North. The area of the solar park is shown in Figure76.

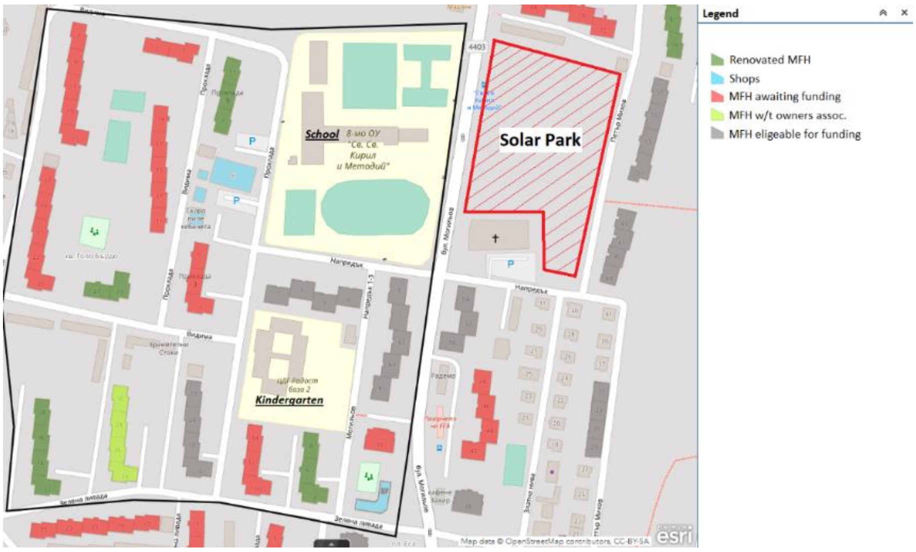


Figure 73: Solar Park Situation.

The plot has an area of 13 410 m^2 and it is almost entirely flat with a negligeable vertical drop of 1 m. Furthermore, there is no shading on the property by neighboring buildings. This report investigates the installation of two fixed systems, each consisting of 1 500 modules. This is done according to the findings in the Regional Plan for Energy Efficiency, where experts explain that because of the increased diffuse light from reflection in the snow cover a fixed system is preferable to a sun-tracking one. The selected panels are Monocrystalline solar panels with a relatively conservative output power of 235 Wp. The systems are installed with 90 degrees deviation from North and with 270 degrees deviation from North.

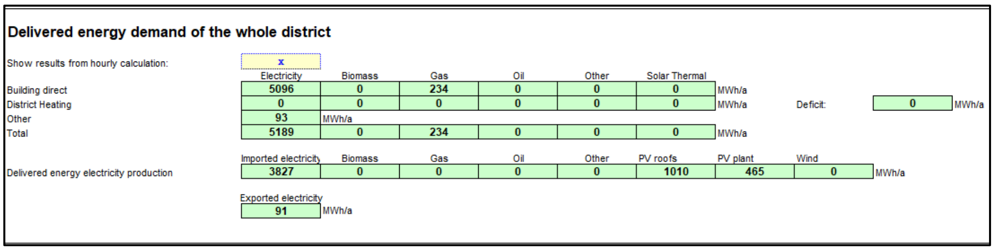
While a solar park on a plot of land is an attractive option for sustainable energy production, it may not necessarily be the best use of that land. Instead, a parking lot or large shop could be built on the land, with the solar park installed on the roof. This approach allows for the land to be used for a practical purpose while still harnessing the benefits of solar power. Additionally, a parking lot or large shop can provide valuable services to the community, such as convenient parking or retail options. By incorporating the solar park into the design of these structures, the city district can maximize the use of its land while still prioritizing sustainability. Ultimately, it is important to consider the practical needs of the community when planning for sustainable energy solutions in urban areas.

Furthermore, in order to maximise the efficiency of the solar plant it is essential to store the surplus energy. This in turn will result in cost-savings, more efficient energy grids, and decreased fossil fuel emissions. This simulation investigates the installation of a short-term storage system made up of Lithium-ion batteries with a capacity of 2MWh. The assumed charging and discharging losses are 5%.

The wind energy potential was also investigated in this renovation scenario. Wind speed is the most important factor affecting the amount of energy, that wind turbines can transform into electricity. Wind turbines use wind speeds between 3 and 30 m/s. Mountain topography of the area does not imply a constant and sufficiently strong wind for efficient power generation. It has been found that the roughness of the terrain, together with the vegetation and buildings on it, are the main factor that reduces wind speed. In the Gabrovo region, there are few places for proper and efficient siting of wind turbines. According to studies the average wind speed in Gabrovo District is below 4 m/s and therefore wind energy production is not a priority for regional development. The best wind resource exists along the coasts and hills. However, for the Gabrovo region it appears that much of the hill terrain suitable for 'capturing' wind power, such as Mt. Bedek and Mt Ispolin, fall within the NATURA 2000 protected areas as they are part of the National Park "Central Balkan" and Nature Park "Bulgarka". Within these areas it is forbidden to build wind turbines, which would lead to destruction of biodiversity. Due to these considerations wind power generation is not considered in this study [Kostadinov 2011].

The simulation was carried out for the whole neighbourhood taking into consideration all the minimum standard component parameters mentioned in Table 4. The calculation model is set up in such a way that a refurbishment is possible evert year. In addition, taking into account the specific country and market conditions, a renovation rate of 10% for the buildings in the district is selected as this is assumed to be the most probable and feasible renovation rate.

The amount of delivered energy that is required to meet the energy needs of the entire district during the year 2072 is summarised below in Figure 77.



Delivered energy demand of the whole district

Show results from hourly calculation: x

	Electricity	Biomass	Gas	Oil	Other	Solar Thermal	
Building direct	5096	0	234	0	0	0	MWh/a
District Heating	0	0	0	0	0	0	MWh/a
Other	93	MWh/a					
Total	5189	0	234	0	0	0	MWh/a

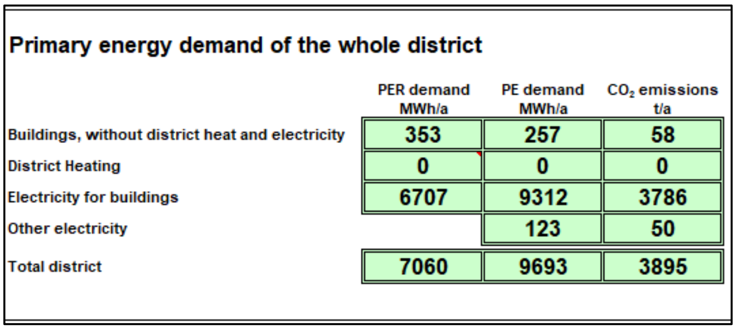
Deficit: 0 MWh/a

	Imported electricity	Biomass	Gas	Oil	Other	PV roofs	PV plant	Wind	
Delivered energy electricity production	3827	0	0	0	0	1010	465	0	MWh/a

Exported electricity
91 MWh/a

Figure 74: Delivered energy demand of the whole district in the year 2072. (Screenshot from districtPH)

Figure 78 shows the amount of primary energy that will be required to meet the energy needs of the district during the year 2072, as well as the amount of carbon dioxide (CO_2) emissions that will result from the consumption of that energy.

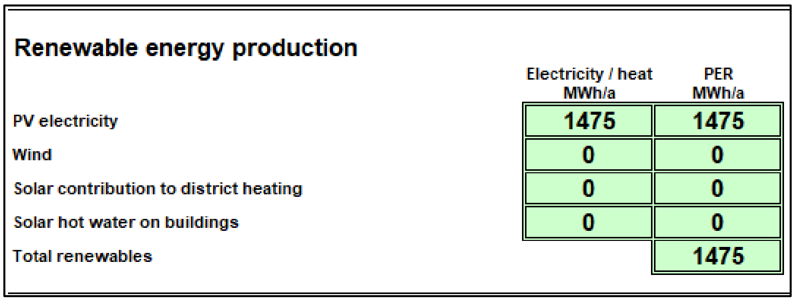


Primary energy demand of the whole district

	PER demand MWh/a	PE demand MWh/a	CO_2 emissions t/a
Buildings, without district heat and electricity	353	257	58
District Heating	0	0	0
Electricity for buildings	6707	9312	3786
Other electricity		123	50
Total district	7060	9693	3895

Figure 75: Primary energy demand and CO_2 emissions in the year 2072. (Screenshot from districtPH)

Figure 79 shows the total renewable energy production in the district from the PV modules installed or the roofs of buildings and from the construction of a solar park.



Renewable energy production

	Electricity / heat MWh/a	PER MWh/a
PV electricity	1475	1475
Wind	0	0
Solar contribution to district heating	0	0
Solar hot water on buildings	0	0
Total renewables		1475

Figure 76: Renewable energy production in the year 2072. (Screenshot from districtPH)

The districtPH simulation results in a photovoltaic potential of approximately 1475 MWh/a for the district. In 2072, the remaining electricity consumption from the grid can thus be reduced from approximately 5189 MWh/a to approximately 3827 MWh/a. Furthermore, the results show that the short-term storage solution using lithium-ion batteries up to 2MWh increase the solar fraction from 37% to 45%. If the batteries storage is increased to 4MWh the solar fraction changes from 37% to 52% contribution of the electricity demand of the district.

Installing solar panels on the rooftops of buildings in the neighbourhood being considered is highly recommended. However, it is not possible to distinguish between greenhouse gas emissions based on renewable electricity generation in the public power grid. We also need to evaluate the benefits and drawbacks of generating electricity locally and accommodating other energy consumers, such as electric vehicles, separately.

4.7. ANALYSIS OF RESULTS

4.7.1. HEATING DEMAND OVER TIME

The results of the refurbishing of the city district are encouraging, as indicated by the significant reduction in heating demand following the renovations. Figure 80 shows that a renovation to the National standards resulted in a heating demand of 32 kWh/m²a, which represents a reduction of more than half from the starting value of 69 kWh/m²a for the district without renovation. However, the most notable reduction in heating demand is seen in the district where the renovations were done up to EnerPHit standards, which resulted in a heating demand of only 9 kWh/m²a. This represents a remarkable reduction of 87% in heating demand, compared to the starting value. These results demonstrate the significant impact of energy-efficient renovations in reducing the heating demand of buildings and improving overall energy efficiency.

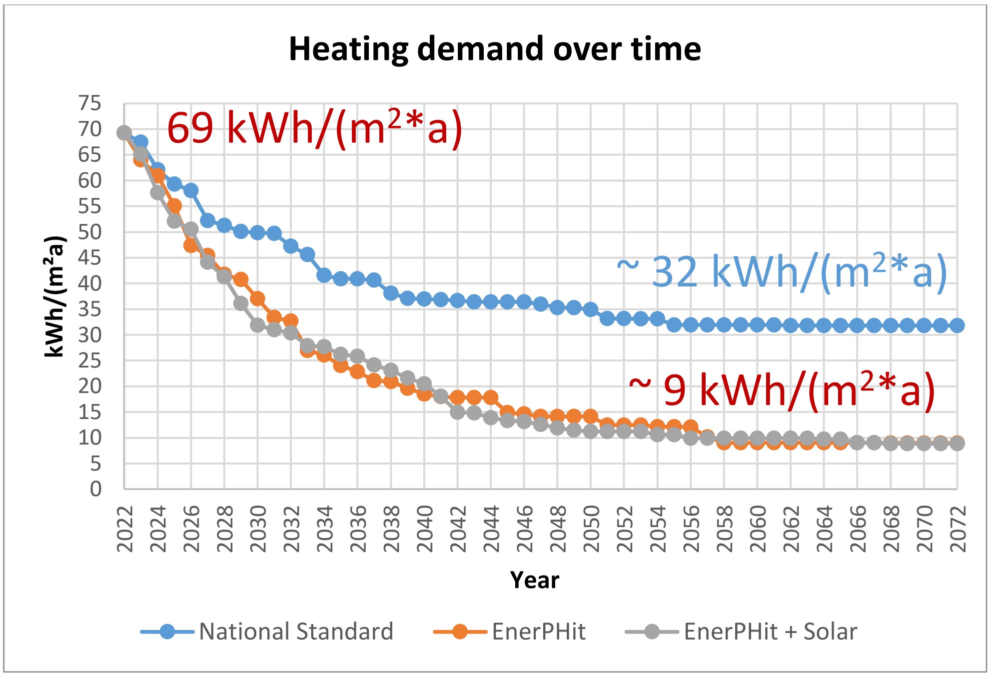


Figure 77: Heating demand over time as a function of the quality standard after refurbishment, specific heating demand at the beginning and end of the period under review. (Own representation)

4.7.2. ELECTRICITY DEMAND OVER TIME

The refurbishment of the city district has demonstrated remarkable reductions in electricity demand, as shown by Figure 81. The starting value for electricity demand was 95 kWh/m²a, which was significantly reduced to 51 kWh/m²a following renovations up to National standards. This represents a reduction of almost half in the electricity demand of the district. However, the most significant reduction in electricity demand was achieved with renovations up to EnerPHit standard, where the electricity demand was reduced to 31 kWh/m²a. This represents a reduction of 67% in electricity demand, compared to the starting value. These results highlight the importance of energy-efficient renovations in reducing electricity demand and improving the overall energy efficiency of buildings.

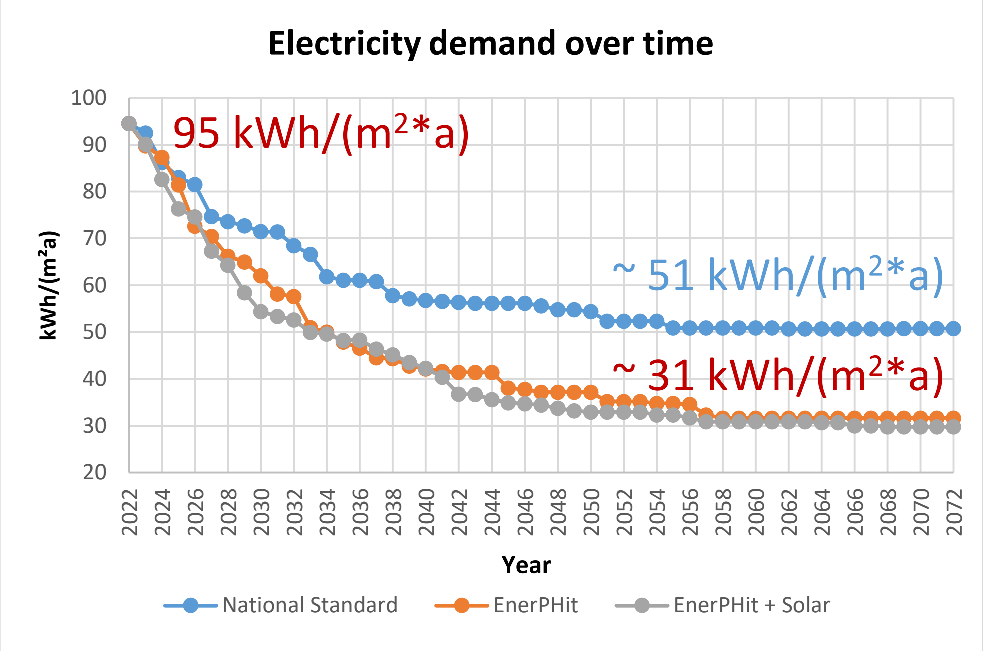


Figure 78: Electricity **demand over time as a function of the quality standard after refurbishment. (Own representation)**

4.7.3. GREENHOUSE GAS EMISSIONS OVER TIME

The refurbishment of the city district has not only resulted in significant reductions in heating and electricity demand, but also in greenhouse gas emissions. The starting value for CO_2 emissions was 12 127 t/a, which was considerably reduced to 7 350 t/a following renovations up to National standards. However, the most notable reductions were achieved with renovations up to EnerPHit standard, which resulted in CO_2 emissions of only 5 491 t/a. Even more significant were the results for EnerPHit renovation with additional photovoltaic modules on the roofs of buildings and in the solar park, which achieved a reduction of 68% in CO_2 emissions to 3 895 t/a. These results highlight the crucial role that energy-efficient renovations can play in reducing greenhouse gas emissions, especially in the built environment. Such refurbishments can help to mitigate the impacts of climate change, improve air quality, and promote sustainable living. Furthermore, the use of photovoltaics can help to increase the share of renewable energy in the district, further reducing the dependence on fossil fuels and contributing to a more sustainable energy system (see Figure 82).

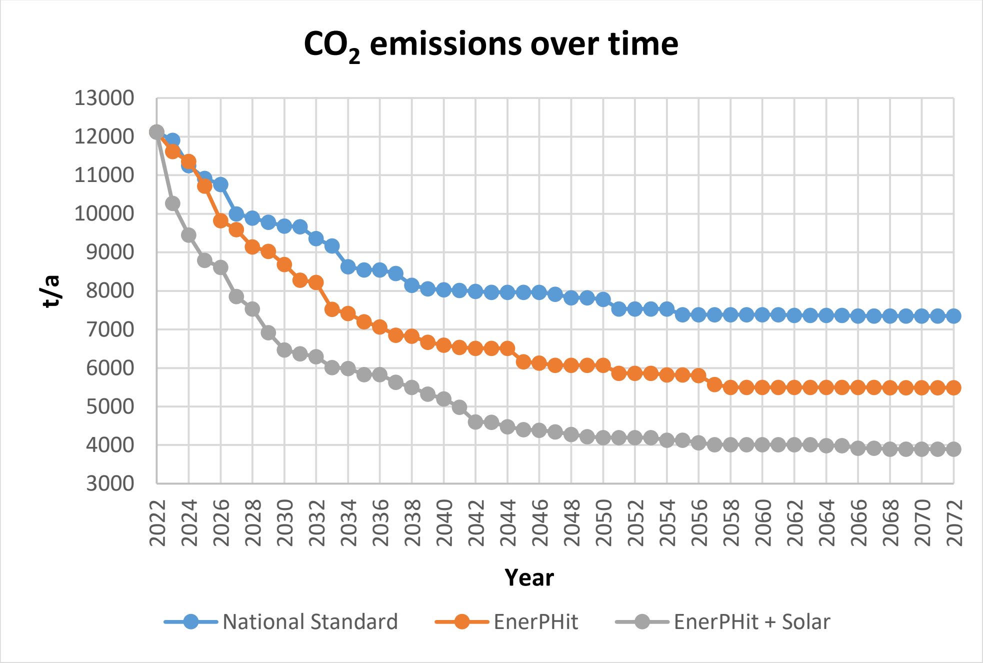


Figure 79: CO_2 emissions over time as a function of the quality standard after refurbishment. (Own representation)

5. GERMANY

5.1. OVERVIEW

The existing building stock plays a key role in the achievement of climate objectives. Above all, this area depends on storable energy sources (still predominantly fossil fuels) which leads to quite significant supply uncertainty, fluctuating costs and political dependence. Climate protection needs lead to the same requirements and the same measures as potential supply shortages to consistently and sustainably reduce the energy demand in the building stock.

Over half of the natural gas utilized in Germany is used solely for space heating. As a storable energy source, in particular, it offers many advantages because the seasonal energy demand arises in winter when the availability of renewable energy is low. Continued use of natural gas as a bridging technology seems appealing, but this is a risk factor that should not be underestimated. Relying on fossil energy cannot ensure with certainty that elementary basic needs such as sufficiently warm rooms will be met, and this constitutes a substantial cost factor in addition. If we wish to make our building stock resilient then this means reducing consumption; with consistent energy efficiency measures, this can be achieved in a sustainable and cost-effective way.

With the present provisions of the German building energy act GEG, it is neither possible to achieve adequate supply security, nor is it necessary for the climate neutrality of the building stock in Germany. The current political coalition has responded to this issue by formulating significantly more ambitious measures and coals in its coalition agreement.

However, this still won't be enough, especially if the efficiency measures (as we have observed so far) are not implemented to the intended extent and quality, or if the proposed expansion of renewable energy use is further delayed. As our study shows, the energy transition in the building sector will succeed if the focus is more consistently placed on the energy efficiency of the buildings themselves: this unneeded energy will no longer have to be obtained and neither will it have to be replaced with renewable energy. This will lead to the independence of politics and consumers and will make buildings resilient. Heating energy is particularly affected because it accounts for a major share of the energy demand in buildings and requires an energy source that is storable, or renewable energy that is shifted from the summer into the winter via storage facilities. Availability in the cold period would also be too low in the case of a renewable energy supply and a high level of efficiency. Additional losses and especially costs will be incurred due to the seasonal storage. Natural gas as a bridging technology is becoming increasingly uncertain, even with the option of switching to renewable gas later on.

In our study we will show that above all, it is a matter of using upcoming measures in the building for carrying out energy retrofits at the same time ("coupling principle"), and at a consistently high quality ("if you have to do it at all, do it right"). The additional investment will then be small, and it will be compensated for by the saved energy costs – that's climate protection not only at zero cost but also with additional profit. This opportunity can be used to undertake measures in addition, which can be implemented quickly as other "low hanging fruits", which will already accommodate dependencies and energy costs in the next winter.

Measures for increasing the energy efficiency of buildings using the Passive House and EnerPHit quality standards are most appropriate for reliably achieving climate goals as well as for supply security for containing costs. The expertise, experience, suitable products and procedures for this are already available. What counts now is good and comprehensible communication, competence/capacity of the trades, widespread acceptance and, where necessary, the right incentives – and especially the avoidance of false incentives. We will provide suggestions for optimisation of these measures in the short term. Mitigation of the social impact of rising energy costs has already been considered in the coalition agreement. Such measures must aim for a reduction in the energy demand instead of further subsidising energy consumption.

5.2. INTRODUCTION

The consequences of climate change can no longer be ignored [IPCC 2022]. Given the importance of this task, in the Paris Agreement countries across the world have already pledged to limit global warming to well under 2 °C and to aim for 1.5 °C. In order to reach this goal, net emission of greenhouse gases must be rapidly and drastically reduced. With unchanged emissions, the remaining budget for the goal of 1.5 °C would already be used up in the next 10 years – calculated from 2020 onwards (see [IPCC 2018]). Consistent with this, Figure 80 shows that emissions must drop to zero in 20 to 30 years.

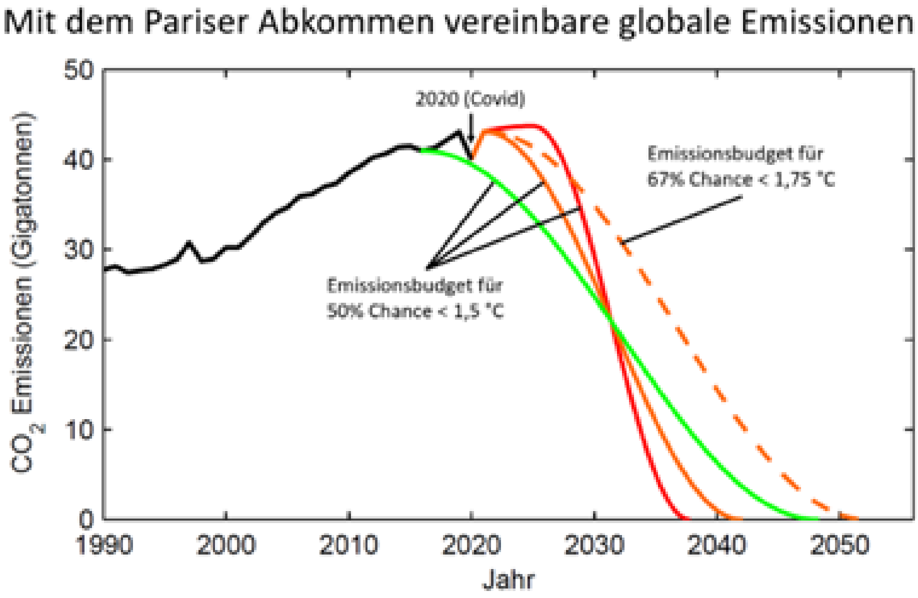


Figure 80: In order to achieve the climate objectives of the Paris Agreement, CO2 emissions must drop to zero by around 2040. Diagram from [Rahmstorf 2020].
Mit dem Pariser Abkommen… =Global emissions agreed in the Paris Agreement

Establishing a new energy supply system cannot happen overnight. If fast action is desired, it will be necessary to make changes on the demand side, in addition to suitable efficiency measures, to make fast action possible. Done properly, these will support the transformation to climate neutrality in the mid-term. With regard to the utilization of the huge potential, however, the building stock is a very slow-moving system, because many of the substantive changes are costly and time-consuming. At present, there are not enough specialists to renew the existing building stock within the space of a few years. It is already clear here that the goal mentioned above can only be achieved if climate protection as well as independence from the fossil energy supply are given the highest priority immediately.

In [Schnieders 2021], it was demonstrated that the German building energy act (GEG), which only came into effect in November 2020, is completely inadequate in this respect. It was also determined here that it is still possible to achieve this goal provided that resolute action is undertaken, and it will even be economically attractive.

The German federal government recently elected in Autumn 2021 has now promised in its coalition agreement [Koalition 2021] that there will be significant changes in the generation of renewable energy and the specification for energy efficiency of buildings. The following analysis shows that the measures adopted in the coalition agreement constitute a substantial improvement compared to the existing GEG and would in theory make it possible to supply the building stock in a climate-neutral way – but only under the condition of full implementation of the optimistic interpretation of the coalition agreement as used here. The climate protection objectives of the Paris Agreement can be achieved more reliably with a significant increase in energy efficiency. That would simultaneously be more economical and sustainable in the long term.

5.3. THE COUPLING PRINCIPLE AND QUALITY OF MEASURES

Building stock is not a static parameter: non-functional or old windows are constantly being replaced (at a rate of approximately 2.7%/a), roof coverings are being replaced (approximately 1.5%/a), façades are re-plastered or re-painted (more than 2%/a). Each of these (and other) measures can be combined with an energy retrofit of the relevant building component – because at that time scaffolding for the construction site will already be needed anyway for example; exposure of the building component which will be necessary for the energy efficiency measure, and renewal of the respective weather protection cover will also be necessary in any case. Ever since the 1980s, in heat insulation ordinances, later on in the energy saving regulations, and today's building energy act, such occasions have been regarded as triggers for so-called "conditional measures". Corresponding thermally relevant improvement is then called for – in such a case, this will be exceptionally cost-effective [Kah 2008]. Of course, non-coupled measures are also acceptable, particularly if there is no reason for the coupling of measures. Above all, willingness and competence are needed here; especially short-term successes may then also be achieved here. In each case, particularly also for the legally formulated causes, it is very important that deep retrofits are carried out to a highly efficient thermal quality, as otherwise another retrofit in the same place usually wouldn't be realistic for many decades, and from the economic perspective its performance would be significantly less favourable. The result would be a lock-in effect which would block the energy transition, and make the achievement of the climate objectives impossible.

5.4. CLIMATE-NEUTRAL BUILDING STOCK IN GERMANY: BOUNDARY CONDITIONS FOR THE ANALYSIS

In order to identify how the climate objectives of the Paris Agreement can be achieved for the building sector, the building stock in Germany was modeled using the [districtPH 2021] tool. First, the selected boundary conditions will be explained in this section.

Different construction year categories, building sizes, and building uses as well as partial heating aspects are considered. In this model, total emissions to the amount of 214 Mt/a CO2 result for heating and hot water in the year 2021.

When the carbon budget is applied to the building stock in Germany in accordance with Figure 80, in order to achieve the target of 1.5 °C this sector may emit around 2 000 Mt of CO2 in total from 2020 onwards. For the target of 2 °C, roughly 3 000 Mt of CO2 would be permissible.

5.4.1. ENERGY COSTS

The electricity generation costs of renewable energy are now of a level similar to those of conventional power plants. Figure 81 depicts this for various electricity generators in detail. While conventional power plants have electricity generation costs of around 12 cents/kWh, wind and PV are already somewhat cheaper. However, because intermediate storage of some of the renewable electricity will be necessary in the future assuming corresponding (market) penetration, this electricity will be just as expensive as conventional electricity at the time it is consumed. In the coming years, the demand for storage will increase, and the number of storage cycles will decrease, resulting in an increase in this cost addition.

Gas turbine power plants ("Gas") are indicated with significantly higher costs in Figure 81. The reason for this is that these power plants are used for short-term, flexible application with an assumed operation duration of only 500 to 3 000 full load hours per year.

Of course, for the end-user, only a part of the electricity price comprises of the electricity generation costs, added to these are the costs for distribution, regulation in the power grid, marketing, charging and last but not least, also taxes. Although this does not play any significant role in the comparison between electricity generation variants, it does have an important role to play in the comparison of alternative options for end-users, such as district heating or solar collectors. If these parts are considered, on the whole it will be reasonable to apply largely stable electricity prices in the future for this study, regardless of the percentage of renewable energy.

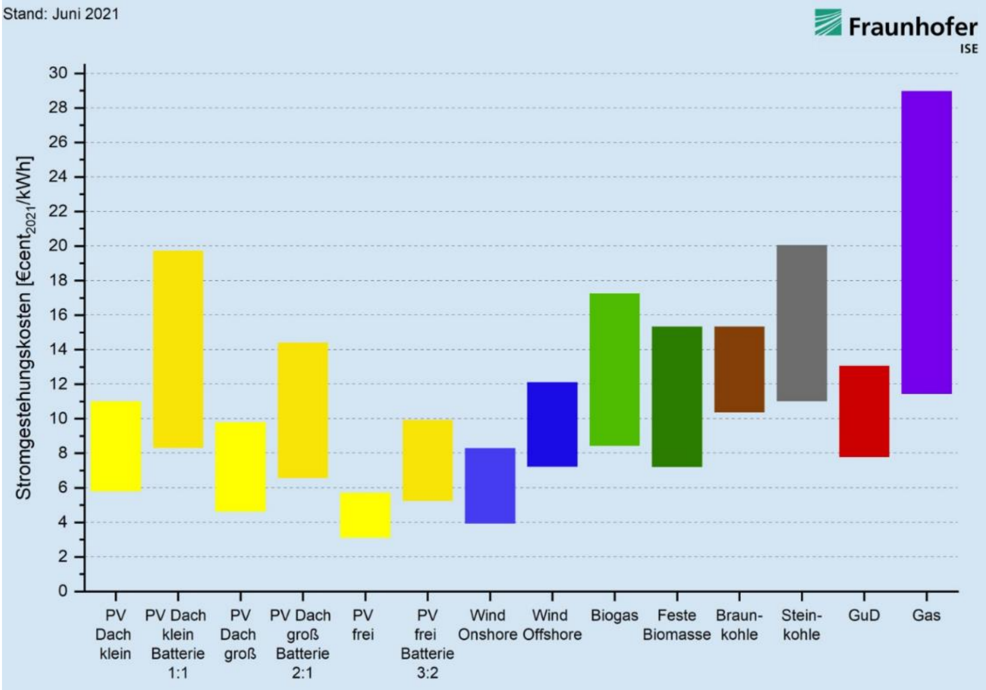


Figure 81: Electricity generation costs in Germany in the middle of the year 2021. Chart taken from [Kost 2021].

In the model used here, the energy prices for the end-user in the future are influenced by the investments in peak-load power plants like the gas turbines and storage technologies mentioned above. These investments are necessary, especially in order to be able to cover the peak loads in winter for electricity consumption which is primarily caused by space heating, despite the low PV availability during this season (see Figure 82). Accordingly, we will assume slightly higher electricity prices in winter: a kilowatt hour of electricity from the seasonal storage, assessed optimistically, costs 10 cents more. This naturally impacts the costs of heating electricity in particular (see Figure 83).

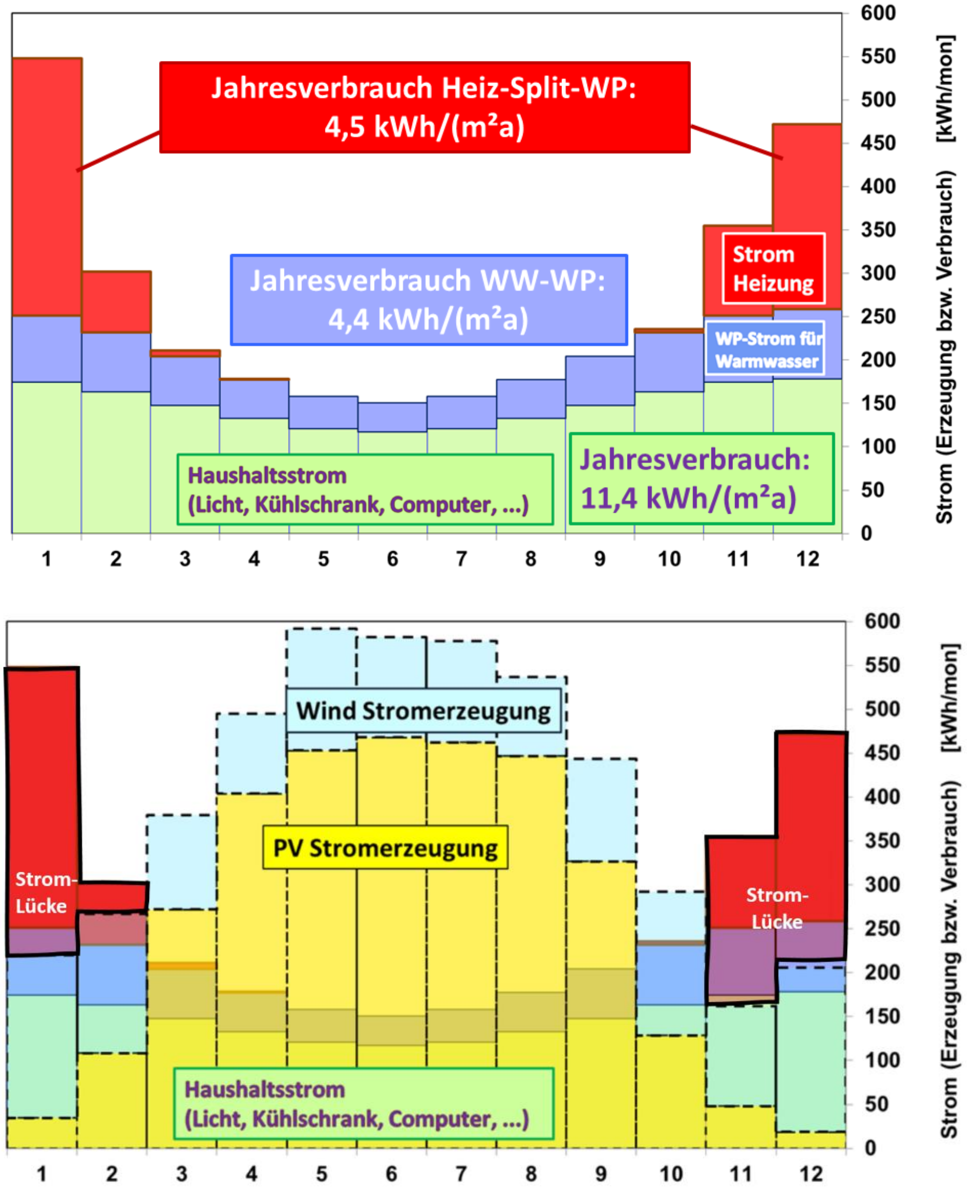


Figure 82: Annual consumption of electricity for all energy applications in the Passive House in Darmstadt-Kranichstein (top) and potential coverage via PV and wind power (bottom). Even with this extremely efficient building, there is a gap between the availability and consumption in the winter; with poorer standards this gap is much larger. This can be closed by means of seasonal storage for surpluses in summer, but this generates storage losses and increased costs. Chart taken from [Feist 2021].

Strom (Erzeugung bzw. Verbrauch)=Electricity (generation and consumption), Strom lücke= gap in electricity generation, Strom Erzeugung=electricity generation, Haushaltsstrom…=domestic electricity (lighting, fridge, computer..), Jahresverbrauch=annual consumption. Heiz-split-WP=heating split HP

The average private consumer price for heating oil over the past 10 years was 7.08 cents/kWh, while that for gas was 6.91 cents/kWh (final energy). These prices are assumed to be constant as a base amount for the future fuel energy price. On top of this, there is initially only a gradual increase due to carbon pricing.

With the change to the Fuel Emissions Trading Act of November 2020 ([Bundesregierung 2020]), a carbon tax was introduced which set the CO2 price to 25 €/t in January 2021. This price will be progressively raised to 55 €/t in 2025. In 2026 the CO2 price will be between 55 and 65 €/t. According to [UBA 2018], the cost of environmental impacts of CO2 emissions is 180 €/t, whereby newer analyses even mention significantly higher costs, particularly if the impacts on the welfare of future generations are equally considered ([UBA 2020]). 180 €/t should also roughly correspond to the future costs for CO2 removal from the atmosphere ([IEA 2021]). Below it will be assumed for the development of the oil and gas prices that with a gradual increase, the CO2 price of 180 €/t will be achieved in the year 2050.

According to [GEMIS 4.95], the CO2 factor for heating oil is 319 g CO2eq/kWh final energy and 250 g CO2eq/kWh final energy for natural gas. Costs of environmental impacts of 5.75 cents/kWh for oil and 4.5 cents/kWh for gas will result if the mentioned price of 180 €/t is assumed. This results in a moderate further increase in fuel prices after 2026. Gradually decarbonized district heating and also biomass are similarly applied to the price development here ("applicable prices": in the future, to some extent, the district heating supply will need additional investment in heat sources with lower CO2 emissions; to what extent these will be financially feasible here also depends on the "applicable price").

For the substitution of energy sources such as gas and oil with renewables (e.g. imported power-to-gas, power-to-liquid) the costs must be set even higher according to [Agora 2018], [Dena 2018], [ESYS 2017] and [ISE 2020] (see Table 55). We will omit that in this study. With the approaches applied here, buildings that are supplied with gas or oil, whatever the origin, are thus assessed rather favourably below in economic terms.

Cents/kWh	Gas 2020	PtG 2050	PtL 2050	Remarks
[ISE 2020]	6	20	24	gross
[Agora 2018]	2.2	10		at the border
[Dena 2018]	1.9	9	12	without transport
[ESYS 2017]		10	10	with transport

Cents/kWh	Gas 2020	PtG 2050	PtL 2050	Remarks
[ISE 2020]	6	20	24	gross
[Agora 2018]	2.2	10		at the border
[Dena 2018]	1.9	9	12	without transport
[ESYS 2017]		10	10	with transport

Table 5: Estimation of costs (cents/kWh) for the import of synthetic power-to-gas or power-to-liquid in the year 2050.

Figure 83 shows the chosen economic boundary conditions.

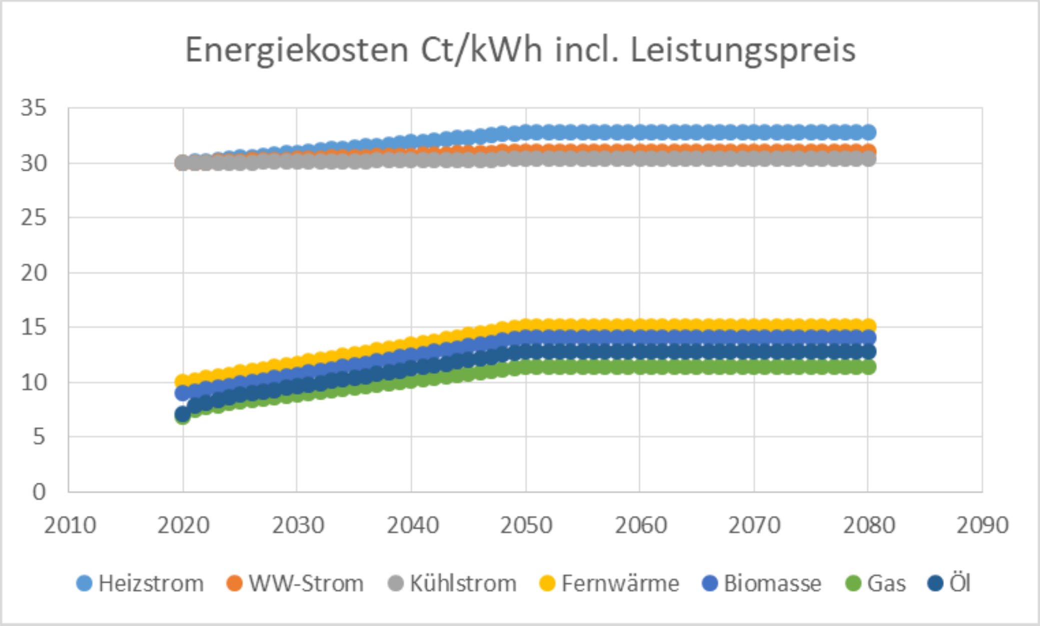


Figure 83: Scenarios with the underlying progression of energy costs for end-users.

Energiekosten incl. Leistungspreis…=energy costs .. including service price

5.4.2. INVESTMENT COSTS

For the arising construction costs, it must be considered that the costs for a specific measure usually consist of two components: business-as-usual costs/costs incurred anyway, which always arise in every case, e.g. when a roof has to be renewed or a window has to be replaced, and the additional costs for increased efficiency, for instance, an additional centimetre of thermal insulation, or the third glass pane in thermal insulating glazing.

In the calculations, only those costs are shown which might differ potentially between the scenarios, therefore these are not the total costs incurred for construction activity, especially in the case of new builds.

The following values were used for the building envelope components (not all intermediate values are stated):

	Business-as-usual costs/ costs incurred anyway	Additional costs for efficiency
Wall	250 €/m²$_{CA}$	1.80 €/m² per cm insulation, λ=0.035 W/(mK)
Roof	253 €/m² $_{CA}$	1.50 €/m² per cm insulation, λ=0.035 W/(mK)
Basement ceiling / floor slab	70 €/m² $_{CA}$	1.25 €/m² per cm insulation, λ=0.035 W/(mK)

Window	336 €/m² $_{CA}$	0 €/m² for U-value 1.2 W/(m²K) 81 €/m² for U- value 0.75 W/(m²K)
Entrance door	387 €/m² $_{CA}$	0 €/m² for U- value 2 W/(m²K) 49 €/m² for U- value 1 W/(m²K) 213 €/m² for U- value 0.5 W/(m²K)
Airtightness	26 €/m²$_{TFA}$	0 €/m² for $n_{50} = 3\ h^{-1}$ 4 €/m² for $n_{50} = 1\ h^{-1}$ 6 €/m² for $n_{50} = 0.6\ h^{-1}$
Ventilation system	28 €/m²$_{TFA}$	0 €/m² for exhaust air system 30 €/m² for ventilation with 80% HRV

CA: component area; TFA: treated floor area, corresponds roughly to the living/useful area within the heated building envelope

The heat supply variants may possibly differ in the following costs:

	Per building	Per m² TFA	Per home	Service life
Gas boiler	9000	23		40
District heating connection	8500	12		50
Heat interface units for district heating			1200	30
Heat pump including geothermal probes etc.	10500	54		20
Heating distribution Radiators	2500	58		40
Heating distribution Underfloor heating	3000	72		50
Hot water system	1725	16		40

5.4.3. RENEWABLE ENERGY

Figure 84 shows the planned expansion of all renewable energy generation in Germany per the 2021 coalition agreement.

According to this coalition agreement, the expansion of PV to 200 GW by 2030 is foreseen. It is assumed that the pace of expansion will be maintained initially in the coming decades. It is difficult to exactly quantify the PV potential in Germany, we have assumed 500 TWh/a here (see also [Wirth 2021]).

The following is planned for the expansion of offshore wind energy: 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045. 120 GW by 2030 is planned for onshore wind energy (see

[Andreae 2021]). Altogether, 80% of the predicted electricity consumption of 680-750 TWh/a annually will be met through renewables by 2030. That would equate to electricity production of approximately 560 TWh/a, which roughly matches the mentioned expansion targets. The total wind energy potential is assessed with 681 TWh/a here (see [AEE 2021] for this).

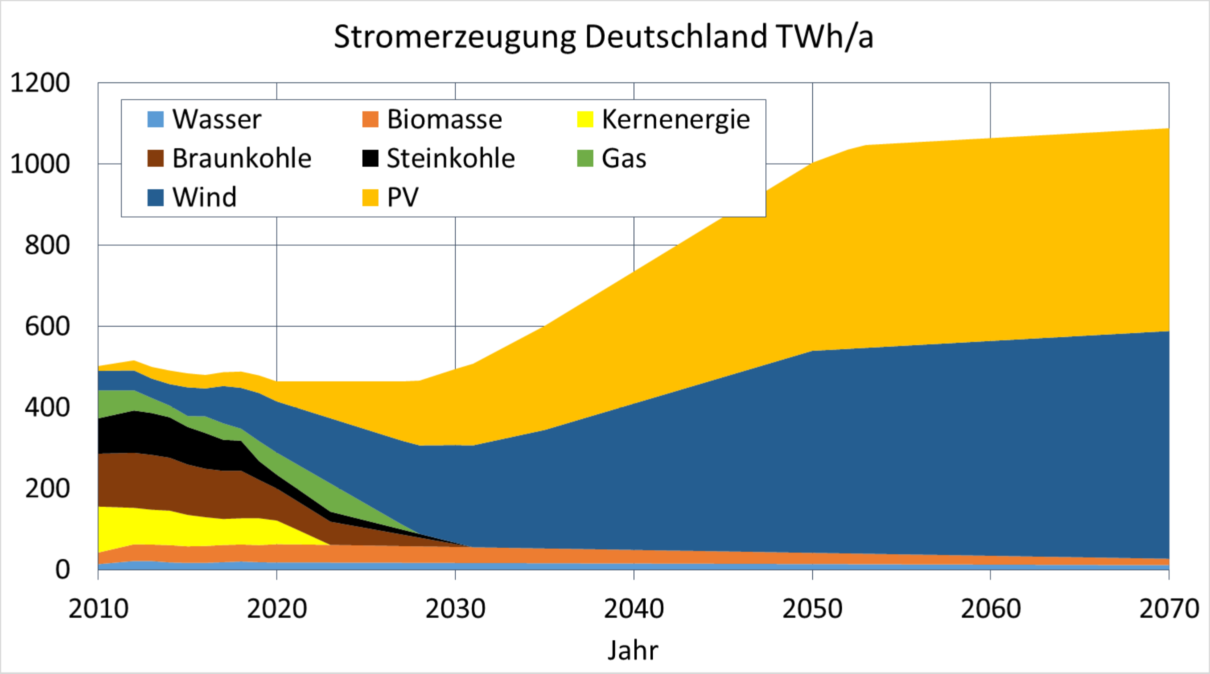


Figure 84: Share of energy sources for electricity generation in Germany. Historically up to June 2021, then projection on the basis of expansion targets of the German government in accordance with the coalition agreement of 2021. The potential for all domestic renewable electricity generation is estimated to be approximately 1000 TWh/a.

Only part of this is available for heating and hot water generation. Based on the current situation, in which a third of the final energy consumption is used for low-temperature heat ([ISE 2020]), we assume that one-third of the renewable electricity generation shown here is available for heating and hot water. In the year 2070, this will be approximately 360 TWh/a of renewables for heating and hot water in the building sector.

In the model, renewable electricity is always used where the most CO2 can be saved. This can be ascertained by employing CO2 and PER factors (see Section 5.6.3 for evaluation using PER, Primary Energy Renewable). For example, if natural gas is replaced with renewable gas obtained through renewable energy (Power-to-Gas, synthetic methane), then 250 g CO2 will be saved per kilowatt hour of natural gas and 1.75 kWh SNG will be required. This results in the following prioritization:

a) cooling
b) electrical generation of hot water (possibly with a heat pump)
c) electrical space heating (generally with a heat pump)
d) generation of district heat
e) generation of renewable gas and substitution of natural gas from fossil sources

f) generation of renewable fuel oil and substitution of fossil-based fuel oil

g) substitute for bioenergy

Consumed electricity which cannot be generated renewably continues to be provided from non-CO2 sources in this model: initially with a power mix (including the current proportion of coal) with 692 gCO2/kWh, reducing to 450 gCO2/kWh for electricity from combined cycle power plants/CCPP by the end of the coal phase-out in 2030.

If more renewable electricity is available than is required, then 250 gCO2/kWh will be credited for this in this paper, which corresponds to use as power-to-heat in place of a gas-fired boiler, e.g. an electrode boiler. Such applications require very low investment costs and are therefore suitable as a standard of comparison. Numerous other applications for saving CO2 – or using the energy for the removal of CO2 from the atmosphere – are conceivable with higher or lower CO2 factors, so the credited amount can only serve as a guide.

5.4.4. EVALUATION STANDARDS

Initially, CO2 emissions are of relevance for a comparative evaluation of scenarios. These are calculated based on the depicted trajectory. With progressing decarbonization of the energy supply, a comparison based on this alone is no longer meaningful. The PER demand would then be a productive criterion for the compatibility and utilization of resources in a sustainable supply based on renewable energy. ([Grove-Smith 2021], [Passipedia 2021]). This indicates how much renewable energy has to be generated to meet the heat demand of the building, including the losses due to storage where seasonal storage is considered. As a third criterion, the costs incurred in each case are of importance for the feasibility and acceptance of the variants.

5.5. SCENARIOS FOR FUTURE PERFORMANCE

Several scenarios will be discussed below. These are not forecasts in the sense of predictions of the actual occurrences; instead, these scenarios show how actions taken today have an impact on future outcomes. This allows informed decisions to be made – without implying this from the outset. First, some simplifications can be made for this.

For example, in all of the scenarios presented here the impact of lowered requirements for buildings listed as historic monuments was not deducted (approximately 5% of residential buildings are classified as historical monuments, in whole or in part; it is still possible to achieve savings here also [Loga 2015]). Differences between the various courses of action are not influenced by this.

5.5.1. GEG SCENARIO

In this scenario, which meanwhile has already become obsolete, we will determine the outcomes that can be expected under the regulations of the German building energy act GEG 2020. The main contribution to the emissions is made not by new builds but by the existing building stock with the present deep energy retrofit equivalent of about 1% per year. Although the actual renovation rate of exterior building components is in the range of 3%/a (see also above), retrofits are not always associated with thermally relevant improvements [Hörner

2021]. In this scenario, we will take this existing implementation deficit and update it: in 40% of the component retrofits, which inevitably take place at the end of the service life, the energy standard of the building component is not improved, while in the remaining cases renovation takes place to the statutory minimum standard (Uwall/roof = 0.24 W/(m²K), Uwindow = 1.3 W/(m²K), no ventilation heat recovery, n50 = 3 h-1 etc.)

On account of the long periods under consideration, demolition (assumed: 0.5% of the respective stock) and new construction are considered. The number of building approvals in 2019 will be updated in the process.

For the heating technology, corresponding to newer empirical data for the building services (see [Hörner 2021]), oil-fired boilers are hardly installed anymore, while gas-fired boilers, biomass boilers, and electrical heat supply (after a renovation this is always a heat pump) are largely retained. District heating is currently converted to gas boilers by approximately 40%, this percentage is also updated in the scenario.

5.5.2. SCENARIOS FOR THE 2021 COALITION AGREEMENT

In the German coalition agreement of November 2021 key points were specified for future regulations relating to the building sector. This resulted in the following boundary conditions:

a) From 2025, only newly installed heat generators which can be operated with 65% renewable energy will be permissible. The concrete definition is still pending, we will assume that new generators in the ratio of 65% heat pump, 15% district heating, 20% biomass will be installed at the end of the service life of an oil or gas-fired boiler. In retrofits, the three last-mentioned energy sources will be retained in each case.[1]

b) Components corresponding with (efficiency class) EH 70 will be stipulated from 2024 onwards. For the EH 70, it is necessary that H'T amounts to 85% of the value for reference buildings according to GEG. This will result in the following average effective U-values:
    a. Exterior walls 0.24 W/(m²K)
    b. Roofs 0.17 W/(m²K)
    c. Building assemblies against the ground 0.3 W/(m²K)
    d. Windows (without thermal bridges) 1.1 W/(m²K)
    e. Exterior doors 1.5 W/(m²K)
    f. Thermal bridge supplement/addition 0.0425 W/(m²K)

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[1] Here we therefore assume that oil or gas fired boilers generally cannot meet the 65% renewables condition. In particular, this means that precisely heating with gas is not labelled as sustainable – the EU taxonomy does not actually provide for this either. However, the corresponding clarification of this fact on the part of the German coalition is still pending. If the coalition does continue to accept gas-fired boilers as a sustainable, permissible option in practice, then the boundary conditions chosen for the scenario here will no longer be applicable.

Installation of ventilation systems with heat recovery does not take place, a n50 value of 3 h^{-1} is achieved in the long term.

c) First, we will examine a situation in which the same implementation deficit exists as in the scenario for GEG ("KV (coalition agreement) 2021, 60% implementation"). In contrast, in the scenario "CA 2021, full implementation" it is assumed that there are corresponding improvements of all components which need to be renovated in any case.

d) In the area of new constructions, EH 40 will become the standard, i.e. a H'T value of 55% of the reference building will be achieved. A ventilation system with HRV is not stipulated (stipulated only for EH 40 Plus). We will therefore also stick with the n50 requirement of 3 h^{-1}.

e) The fact that building standards must only be improved from 2024/2025 onwards according to the coalition agreement will be disregarded here. Because of the long-time scales, the influence is small and a transitional period would be necessary even for alternative standards. However, this approach is also optimistic.

f) The heating systems in new builds will be selected in the same ratio of 65:15:20 electricity: district heating: biomass as after a retrofit.

For an improvement to result in comparison to the GEG scenario, it is of crucial importance that the requirement for H'T remains in place. With the "renewable" heat generators already stipulated in the coalition agreement, the PE requirement alone would often already be met with the GEG 2020 standard (or close to this).

For new builds, a requirement for the area-specific heating energy demand is more effective than the H'T requirement. This will have the advantage that favorable orientations and cubatures which reduce the energy demand have a positive impact on the verification, and costs and use of grey energy will be reduced as a result.

5.5.3. SCENARIO FOR ENERPHIT/PASSIVE HOUSE STANDARDS

EnerPHit is short for "energy retrofits using Passive House components in existing buildings". This can also be carried out in a staged process where necessary in case of replacement or repair of building assemblies. More details on this can be found in [Passipedia 2021a].

In this scenario, the focus is on Passive House quality whenever a component needs to be renewed anyway. In terms of implementation speed, this variant, therefore, corresponds to the scenario for the 2021 coalition agreement, an implementation deficit is not assumed here. For this scenario, new construction takes place to the Passive House Standard. These measures are already cost-effective in themselves (see [AK 55]).

The good quality of the building envelope facilitates the transition to electric heat pumps as the heating system, both in the individual case (smaller heating load, lower necessary forward flow temperature, and therefore lower investment) as well as in regard to the network and generation capacities. For this reason, heat pumps have a higher share in heating system renewal here: when a heating system based on gas, oil, or biomass is renewed, heat pumps are used in 90% of the cases, while district heating connection is used in 10% of the cases. As a consequence, in the year 2070, almost two-thirds of heat generation (concerning the final energy demand) will rely on electric heat pumps, with district heating accounting for the rest.

As a further improvement compared to the coalition agreement scenario, it is necessary to mention the more efficient hot water generation that is foreseen here. With a heat pump-based supply system, decentral heat pumps will be used, while heat interface units will reduce the distribution losses of a district heating-based supply system.

5.5.4. SCENARIO CA 2021, ACCELERATED

Here, the renewal rate for all components which do not have the necessary level of efficiency will be accelerated over the coming 10 years in such a way that they are already improved after half of their service life rather than at the end of their service life. In this way, a complete deep retrofit of the existing building stock will already be achieved by 2050.

5.5.5. SCENARIO CA 2021, ONLY HP/DH

For the reference case of the 2021 coalition agreement, heat supply will take place with bioenergy in part. However, bioenergy is particularly suitable for closing the gap between generation and demand on account of its natural storage capacity. At the same time, its availability is limited to an even greater extent than PV or wind power for example. Valuable bioenergy can be used most efficiently in CHP plants, particularly at times when electricity from renewables or short-term storage is not available.

Similarly, to the scenario for the EnerPHit/Passive House standards, it will therefore be examined what effects the boundary conditions of the coalition agreement will have if heat supply takes place with direct utilization of bioenergy (see [UBA 2022]).

5.5.6. SCENARIOS WITH SLOWER EXPANSION OF RENEWABLE ENERGIES

It is not guaranteed at all that the ambitious trajectory for renewable energies can be implemented as planned in the coalition agreement or that the assumed percentage of renewables will be available for space heating and hot water generation. The two scenarios CA 2021, full implementation, 50% RE and EnerPHit/Passive House, 50% RE were therefore calculated as a sensitivity study, in which only half the renewable energy is available in each case.

5.6. COMPARISON OF RESULTS

5.6.1. HEATING ENERGY DEMAND

As Figure 85 shows, in the EnerPHit case, the heating energy demand declines slowly but in a sustained manner. Up to 2045, the value is halved, from 2070 a saturation of the initial value is reached at approximately 25% if no further technical progress is achieved. In the past, there has always been such progress, and it is also already foreseeable for the future. We will therefore remain significantly on the safe side here, particularly for the time after approximately 2035. In other words: in this case, the future looks even more favourable in reality. Nevertheless, it is also clear that unless importance is attached to improved efficiency specifically, such progress cannot be achieved on a large scale.

In the GEG scenario in comparison, a completely insufficient reduction is recognizable. By contrast, the scenarios for the coalition agreement already represent a considerable improvement; here the heating energy demand also goes down, although not as strongly as in the EnerPHit-scenario. The reason for this lies mainly in the clearly too weak EH 70 standards for existing buildings. The new builds in accordance with EH 40 are also less efficient than in the EnerPHit/Passive House case, due mostly to a lack of mechanical ventilation with heat recovery and the poorer level of air tightness.

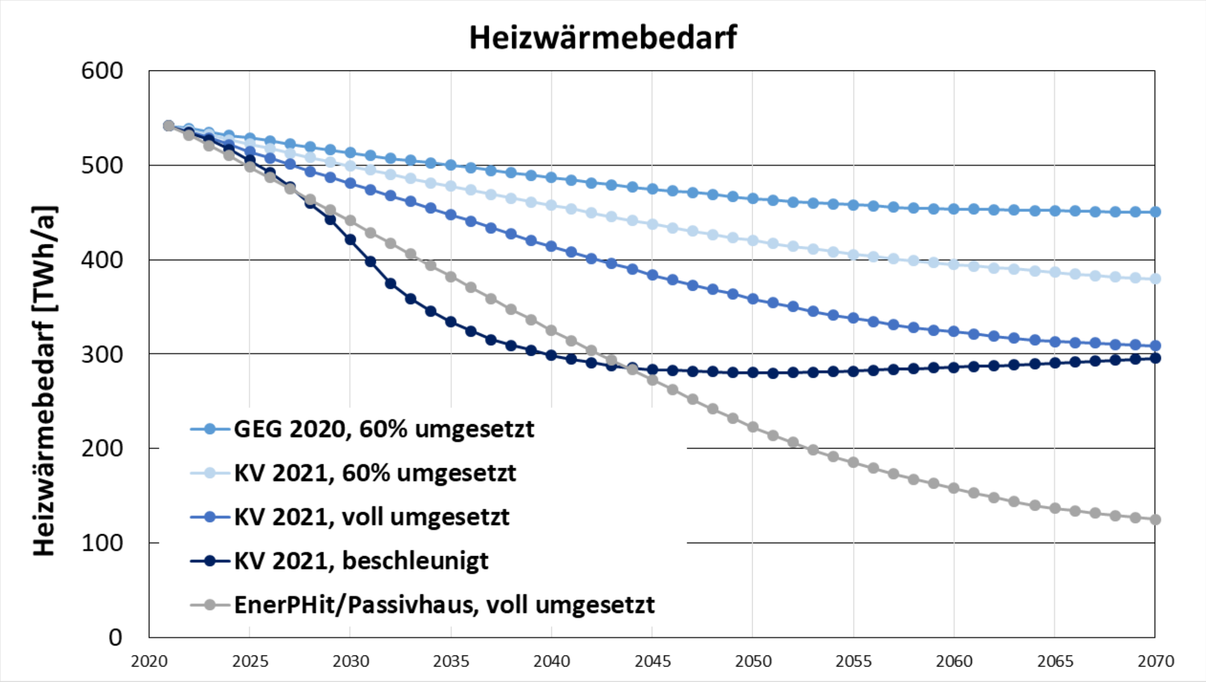


Figure 85: Heating energy demand in the scenarios studied. With the EnerPHit/Passive House scenario, a 75% reduction of the demand is possible by 2070 The targets decided in the coalition agreement lead to a smaller reduction, whereby the implementation speeds differ considerably depending on the scenario.

KV=CA, umgesetzt=implementation, beschleunigt=accelerated, voll umgesetzt=full implementation, Passsivhaus=Passive House, Heizwärmebedarf=heating energy demand.

At this point it must be noted that all results inevitably have certain accuracy limits; these can be estimated to be around ±50 TWh/a here, whereby the differences between the scenarios are only around half of this since they are determined under otherwise constant boundary conditions (ceteris paribus).

5.6.2. CO$_2$ EMISSIONS

The significantly accelerated expansion of renewable energies compared to earlier strategies leads to an almost climate-neutral building stock being achieved from approximately 2050 onwards (Figure 86) in all examined cases except for the GEG scenario. In combination with Figure 87, it is apparent that:

a) Compared to previous statutory requirements, improvements are foreseen with which the envisaged objectives can be achieved in theory (compare GEG 2020 with the other variants).

b) The consistent implementation of improvements with every renovation that is carried out is crucial to reducing greenhouse gas emissions (compare CA 2021, 60% implementation with Ca 2021, full implementation).

c) The small CO2 factor of biomass (20 g/kWh) contributes to this result to some extent; however, even in relation to the entire energy system, this does not acknowledge the fact that biomass is a scarce resource with many other fields of application, see also Section 5.6.3. Replacing the fuel consumed in the biomass boiler with other renewable energies is very inefficient; an electricity surplus will result and negative CO2 emissions will become possible only if bioenergy is not used in the base load (compare CA 2021, full implementation with CA 2021, only HP/DH).

d) The EnerPHit/Passive House variant reaches climate neutrality a few years earlier. After that, less energy will be consumed in the building sector than the amount of renewable energy available for this purpose. The emissions become negative: CO2 can be retrieved from the atmosphere using surplus energy.

e) Due to shortened renovation cycles in the CA 2021, accelerated variant, emissions can be reduced faster in theory, however, the practicability of this is highly debatable (see below).

f) It is not unlikely that in 2050 and later, less renewable energies will be available for low-temperature heat in the building sector than previously estimated, e.g. because the expansion of renewables could not be implemented to the desired extent and larger percentages are consumed in other sectors. For this reason, the maximum possible efficiency must already be achieved today at every opportunity. With 50% renewables available, climate neutrality will only be reached with the EnerPHit/Passive House variant.

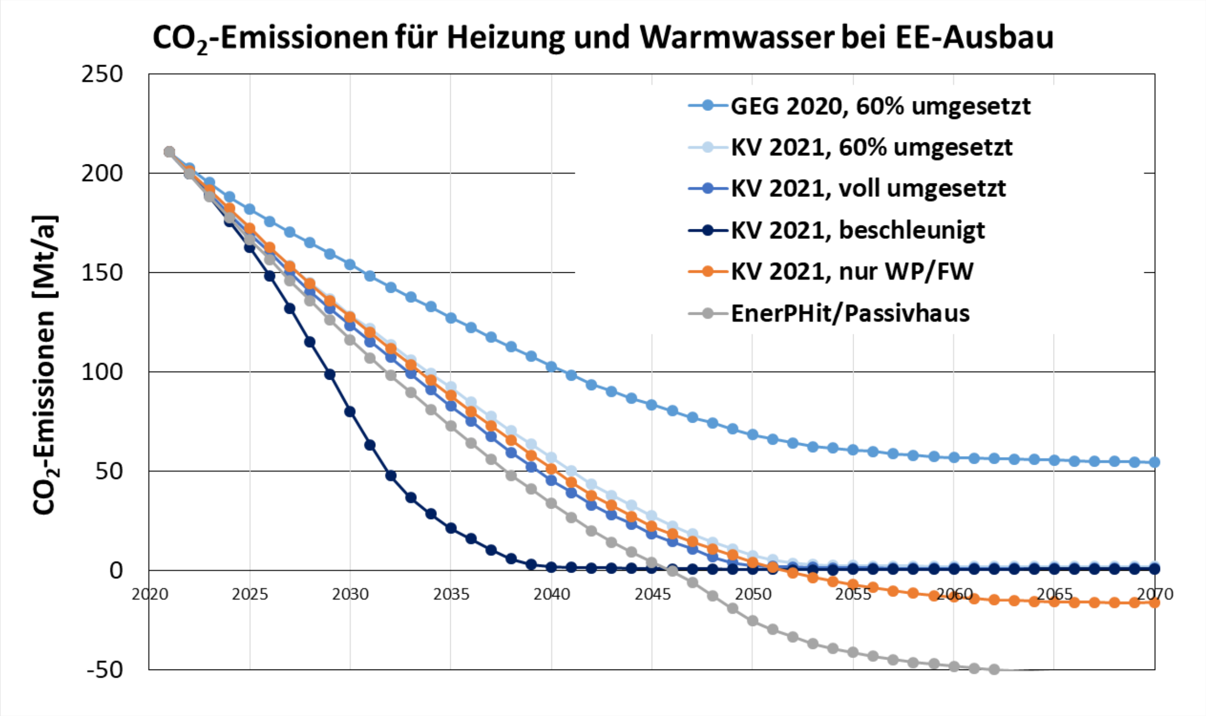


Figure 86: Development of CO2 emissions in the studied scenarios.

CO2-Emissionen für Heizung…= CO2 emissions for heating and hot water with the expansion of RE, nur WP/FW=only HP/DH

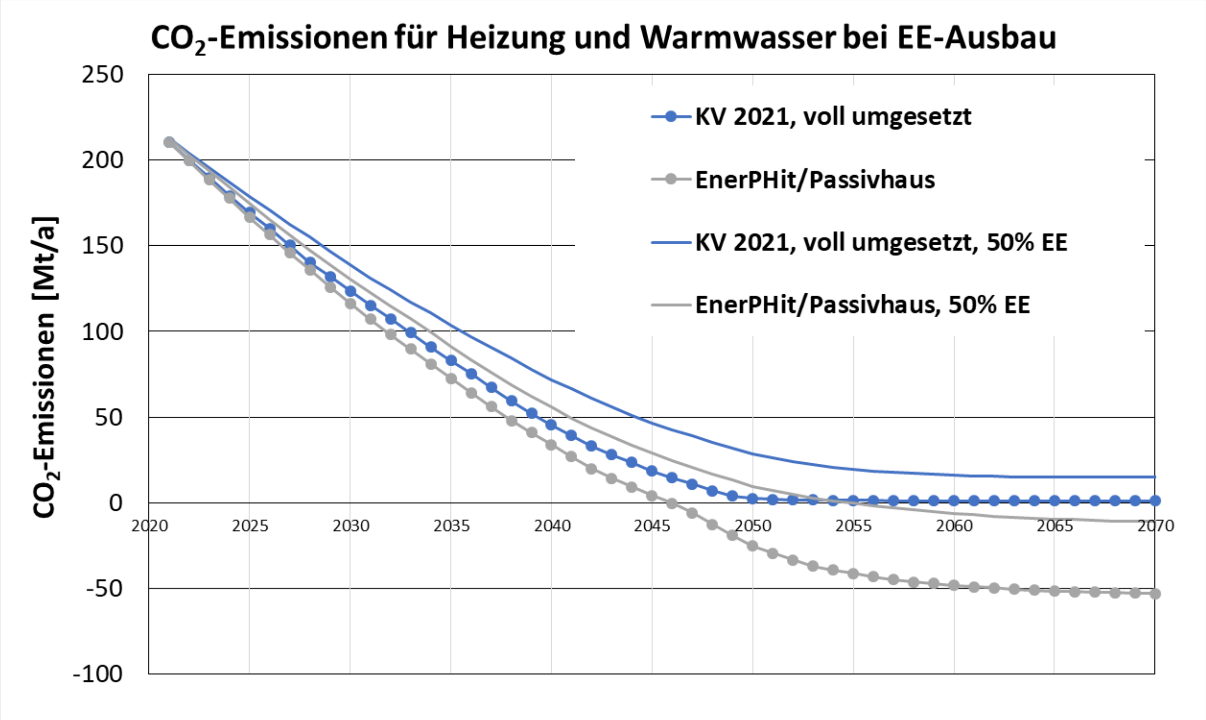


Figure 87: Development of CO2 emissions in the studied scenarios with 50% renewable energy availability.

The cumulated CO2 emissions for heating and hot water over the next 50 years convey the same message (Figure 88). The target of 1.5 °C will only be achieved in two of the scenarios

(EnerPHit/Passive House and CA 2021, accelerated). However, if rapid expansion of renewable energy succeeds, the results (except for the case of GEG 2020, 60% implementation) will still be compatible with the 2 °C targets for maximum global warming of the Paris Agreement.

In the long term, measures will likely have to be undertaken for reducing the excessive CO2 content in the atmosphere. In the EnerPHit scenario, there is scope for this from approximately 2050 onwards due to renewable energy surpluses that will become available due to this.

A high level of efficiency at the Passive House level demonstrates its advantages here. Except for the unrealistic "accelerated" scenario, the lowest emissions over the next 50 years can be achieved with this. Even if the expansion of renewable energies were to progress more slowly, an acceptable outcome will still be achieved with this.

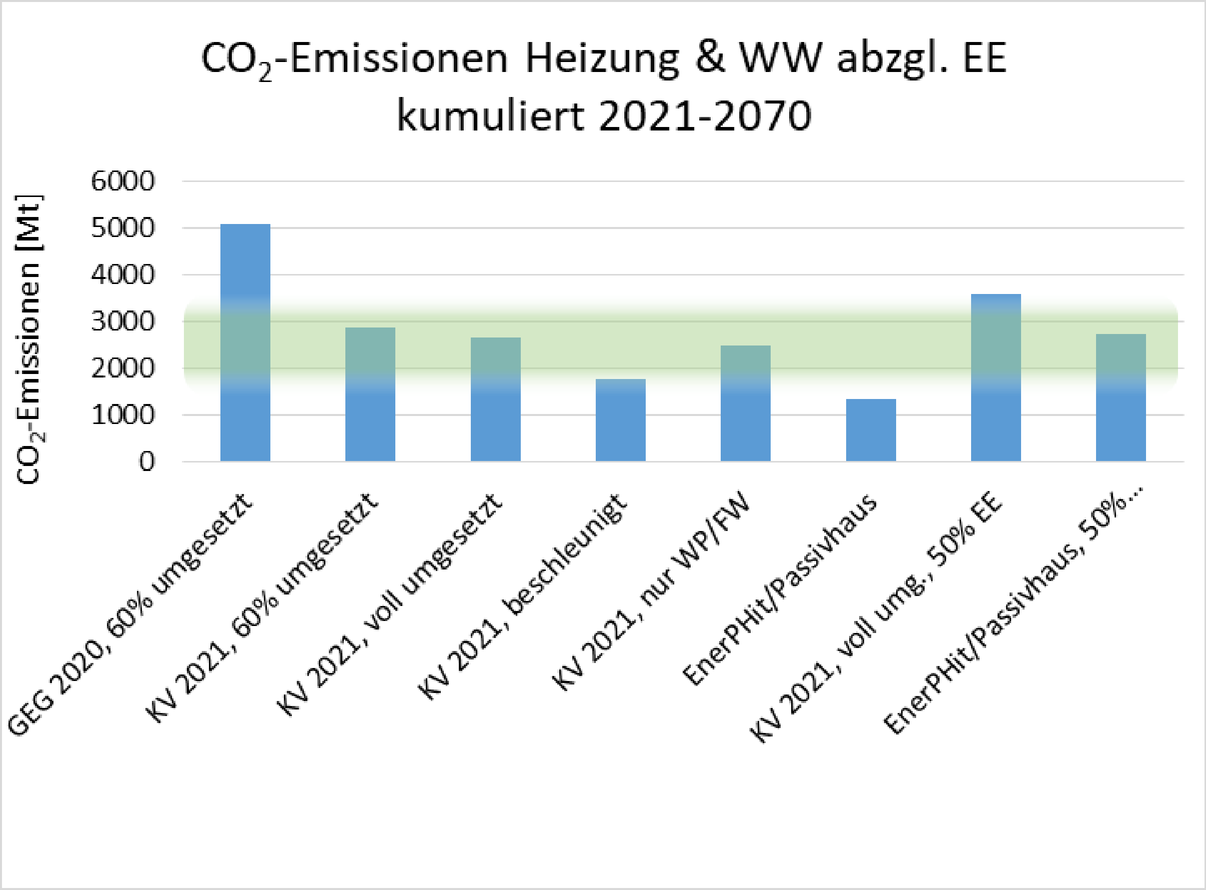
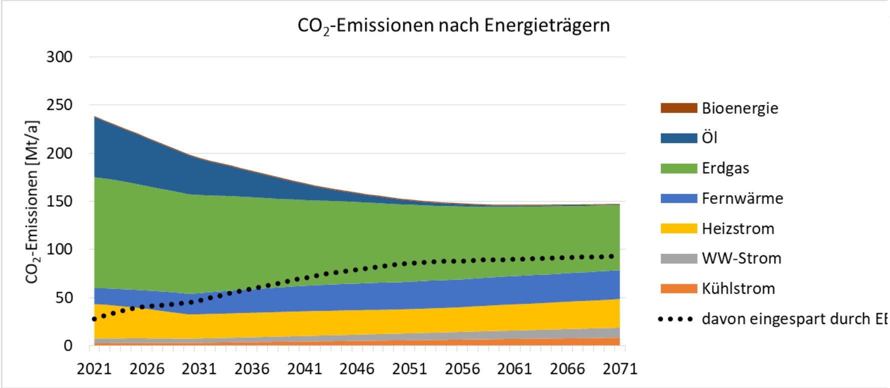
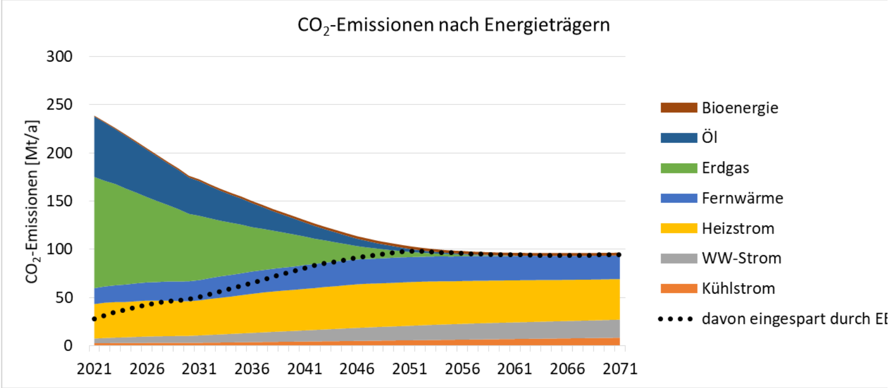


Figure 88: Total CO2 emissions from 2021 till 2070. The green band indicates the greenhouse gas budget that is still available (1.5° to 2° global warming).

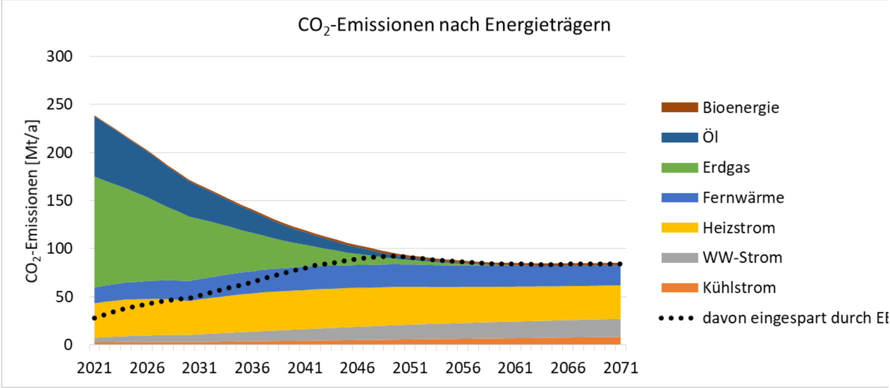
Figure 89 and Figure 90 show how CO2 emissions are allocated to different energy sources. A large proportion of gas heating remains with the GEG variant, which will still have to be covered almost completely through fossil sources in 2070 – despite the massive expansion of renewable energies. Incidentally, the same would still apply if natural gas heating was classified as "sustainable" (contrary to physical facts) by politics. The EnerPHit variant at the other end of the scale in contrast would still release relevant reserves in around 2050, which can be used for other purposes – for example for the likely case that 100% implementation is not achieved.



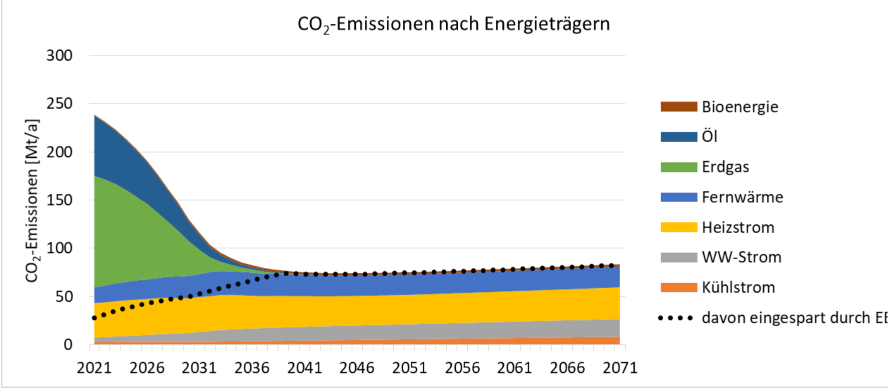
GEG 2020, 60% implementation



CA 2021, 60% implementation



CA 2021, full implementation



CA 2021, accelerated

Figure 89: Make-up of CO2 emissions for the first four cases .

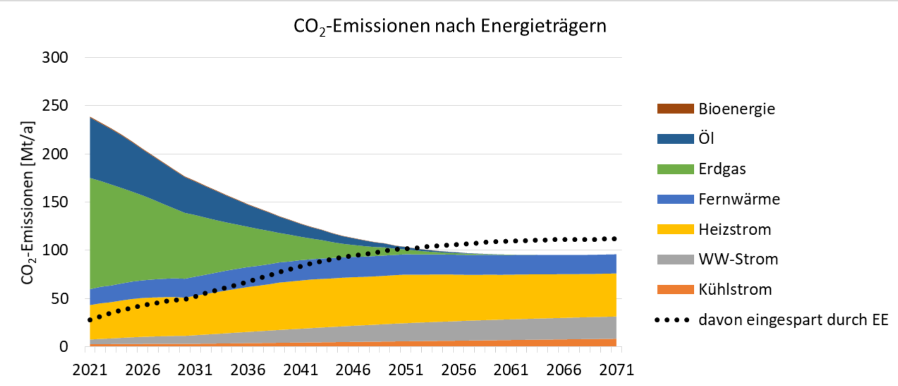
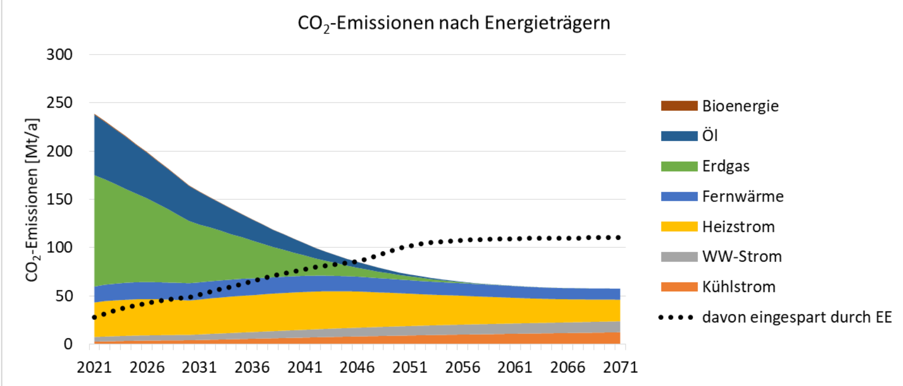
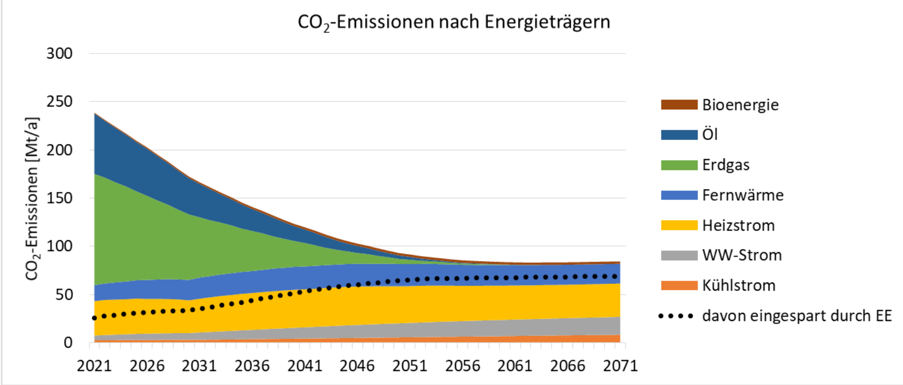
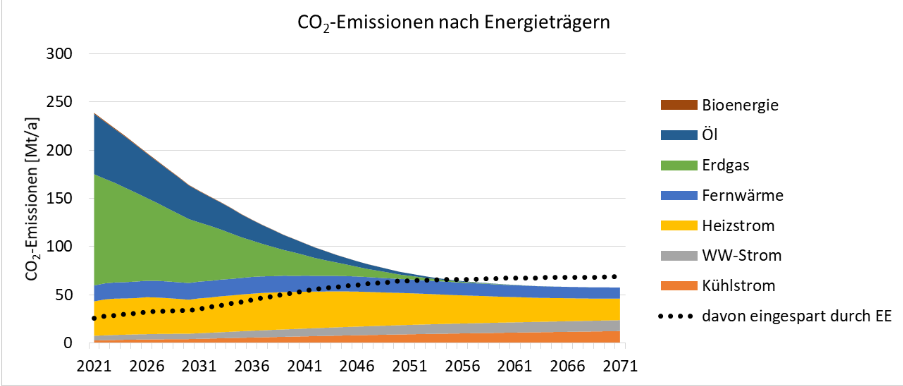
	CA 2021, only HP/DH
	EnerPHit / Passive House
	CA 2021, full implementation , 50% RE
	EnerPHit / Passive House, 50% RE

Figure 90: Make-up of CO2 emissions for the last four cases.

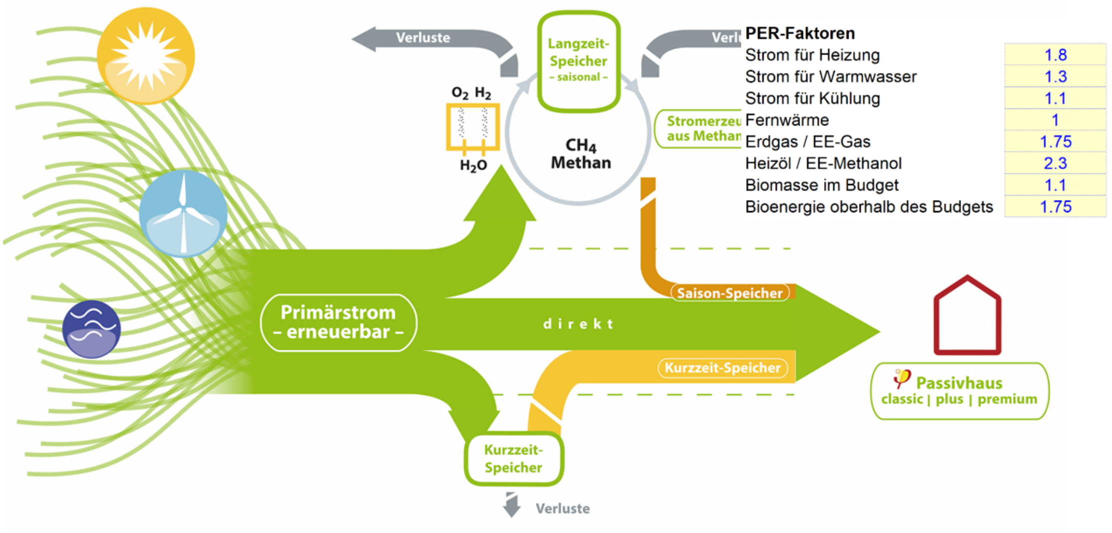
5.6.3. PER DEMAND

Primary Energy Renewable (PER) is a measure of the expenditure for renewable energy which is needed for a specific energy application. Renewable energy is mostly available in the form of electrical current, but not in the amount in which it is required. As illustrated in Figure 91, only a part of the renewable energy electricity from solar, wind, or hydropower can be directly consumed. A part must be stored over a few days for example; this may be done utilizing batteries or pumped storage plants. These storage facilities have an efficiency of around 70%. Besides this, it is necessary (see also Figure 82) to store a part of the electricity generated in the summer for use in the winter. This is possible through the generation of hydrogen or methane from renewable electricity; however, the efficiency here is only 28%. Accordingly, an especially high amount of renewable primary energy must be generated for heating electricity in the winter.

Other energy sources can likewise be generated from electricity. In the case of gas, electrolysis and mechanization are necessary for this. One kilowatt hour of gas requires 1.75 kWh of primary energy.

Bioenergy as a renewable energy source is assessed with a PER factor of 1.1. However, limited availability must be considered; above the budget of 20 kWh/(m²a) "bio" energy in reality is generated via PtG with a PER factor of 1.75.

District heating may use a variety of heat sources depending on availability, some of which have very low PER expenditure. With appropriate efforts, a PER factor of around 1 is achievable.



PER-Faktoren	
Strom für Heizung	1.8
Strom für Warmwasser	1.3
Strom für Kühlung	1.1
Fernwärme	1
Erdgas / EE-Gas	1.75
Heizöl / EE-Methanol	2.3
Biomasse im Budget	1.1
Bioenergie oberhalb des Budgets	1.75

Figure 91: Basic concept of the PER system: electricity must be stored over different time periods, which gives rise to losses and costs. The table on the right shows the PER factors applicable in Germany.

Figure 92 shows the PER demand of the different scenarios at the end of the period under consideration, in the year 2070. There are drastic differences between the variants. The scenarios with a high percentage of biomass but moderate efficiency (CA 2021, 60% implementation; CA 2021, full implementation; CA 2021, accelerated), perform less well here. The bioenergy budget of 20 kWh/(m²a) in the year 2070 corresponds to a total of 145 TWh/a.

The calculated biomass demand in the case of CA 2021, full implementation is 115 TWh/a and is still within the scope of such a budget. Nevertheless, PER demand results are significantly higher than in the variants in which HP/DH prevail – appropriately because bioenergy is now missing for effective use in the generation of electricity and district heating in the winter. The EnerPHit/Passive House variants perform particularly well as they require less seasonal storage and therefore incur fewer losses due to the smaller heating energy demand.

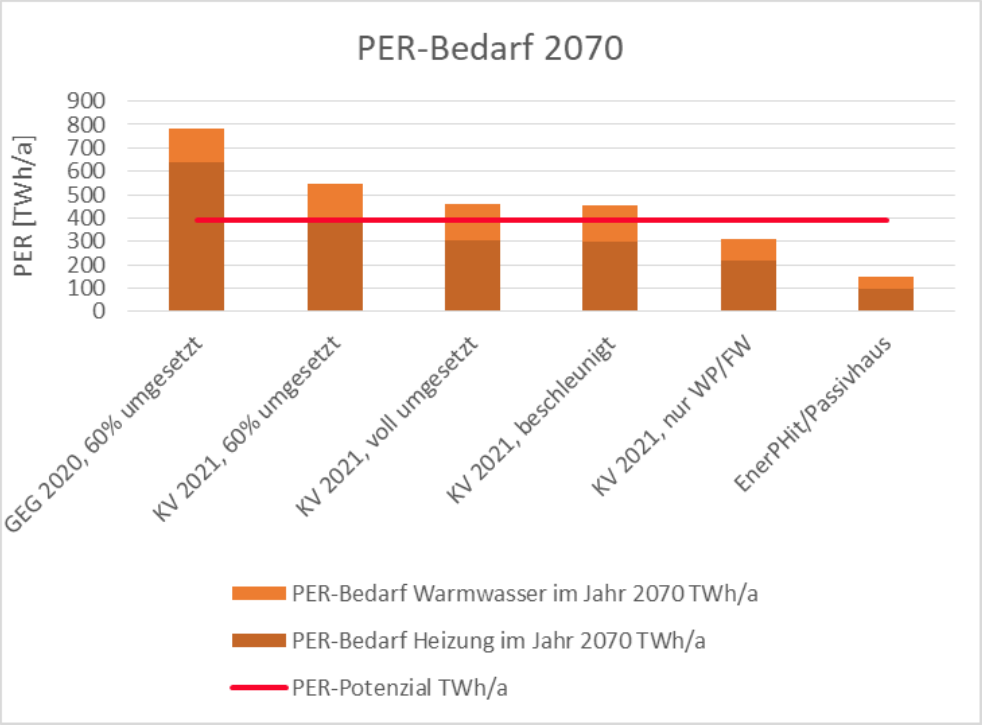


Figure 92: Annual PER demand at the end of the period under consideration.

5.6.4. COSTS

The total costs for the energy demand plus energy-relevant measures (Figure 93) are higher in the case of CA 2021, full implementation than in the EnerPHit variant; the overall higher energy demand is noticeable here. In the EnerPHit scenario, moderately higher investment costs are necessary, but these are more than compensated by the saved energy. The difference in the total costs (present value) in both cases is 610 billion euros. As already explained, the costs mentioned here relate exclusively to the energy-relevant portions of the measures.

High overall costs are incurred if the efficiency is not significantly improved as in the first two variants. The accelerated scenario is particularly costly, with 1500 billion euros more than the EnerPHit variant: in this, residual values are destroyed to a considerable extent due to the relatively rapid renewal of building components that are still functional. This also means an increase in the manufacturing energy demand and the CO2 emissions associated with this. We have not included these here because they play a role only in this specific scenario and otherwise remain below the accuracy margin of the model calculation. In the other scenarios, replacement measures are largely only undertaken in the normal renewal cycle, in which case the differences in the manufacturing energy are small (e.g. replacing a gas boiler with an electric heat pump). The situation is different if the boiler is to be replaced ahead of time – then its full manufacturing expenditure will be incurred before energy production has switched to sustainable energy sources to a large extent. The earlier a measure is applied, the more harmful the use of manufacturing energy will be to the climate.

Figure 94 shows when the additional costs are incurred in the accelerated scenario. Huge sums would have to be invested in the existing building stock within the space of a few years. For comparison: Germany's total public budget for 2020, including social insurance was 1700 billion euros, and the gross domestic product was 3300 billion euros.

The practicability of accelerated deep retrofits stands in opposition to the capacity, especially in the construction industry. This employs around 2 million people in Germany, with a turnover of approximately 400 billion euros annually. The trajectory sketched in Figure 94 would increase the share of energy-related costs recorded here by approximately 120 billion euros, that is about 30% of the total volume in the building sector within the space of a few years; about 600,000 construction workers plus the necessary specialists for the complex field of existing building retrofitting would have to be available at short notice. It must also be kept in mind that in line with the investments, the big wave of modernization may lead to mass layoffs in the construction industry from the start of the 2030s because after the premature retrofits there will be a significantly reduced demand over a few decades. Such a scenario would be suboptimal both in terms of the national economy and social policy. However, at present precisely these boundary conditions are changing: dependency on fossil fuel natural gas as a "bridging solution" may turn out to be an illusion not only concerning the achievement of the climate goals but also in geopolitical terms. Of course, to a certain extent, the energy demand of the existing building stock can be reduced in the short-term using financial means, and at a quicker pace than would be possible through the expansion of the renewable energy supply. To this end, it is necessary to identify measures that can be rapidly and cost-effectively implemented with a greater impact on the reduction of the heating energy demand.

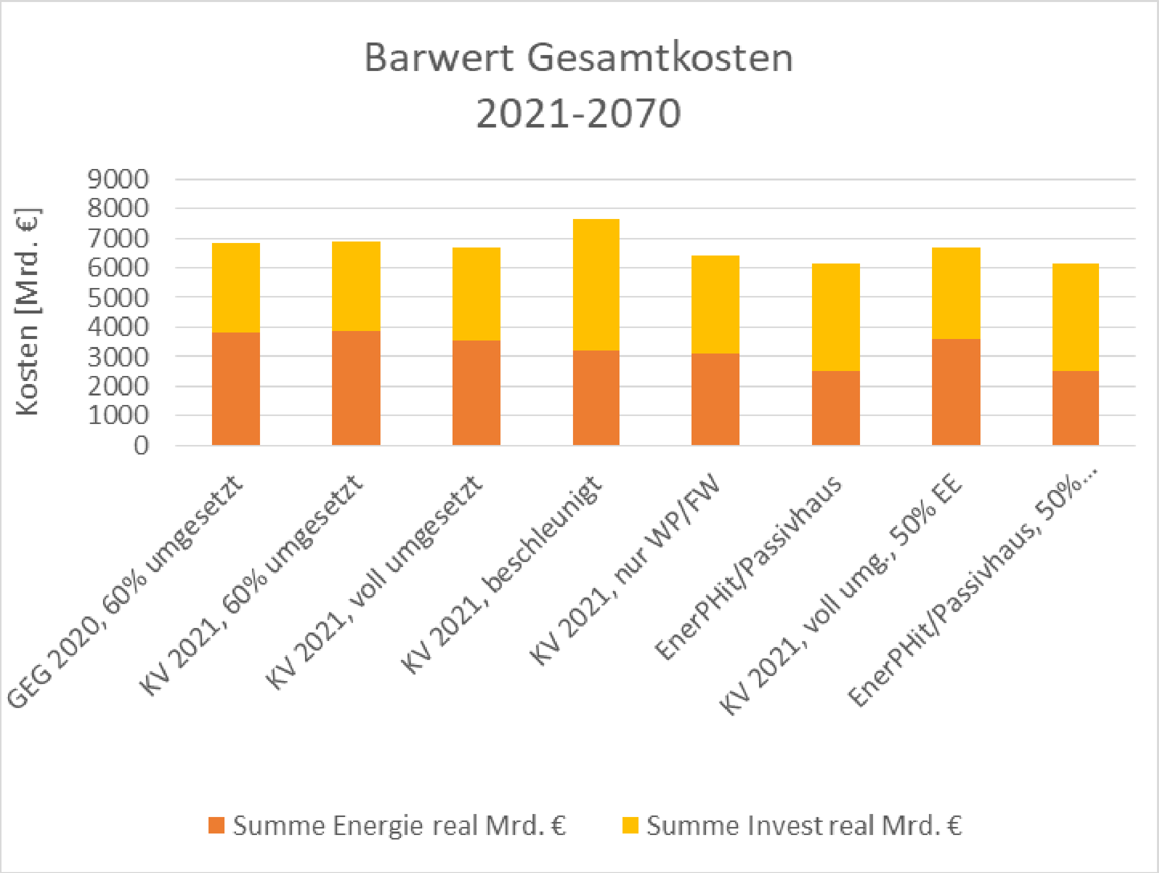


Figure 93: Energy and investment costs for energy-relevant measures in the studied scenarios.

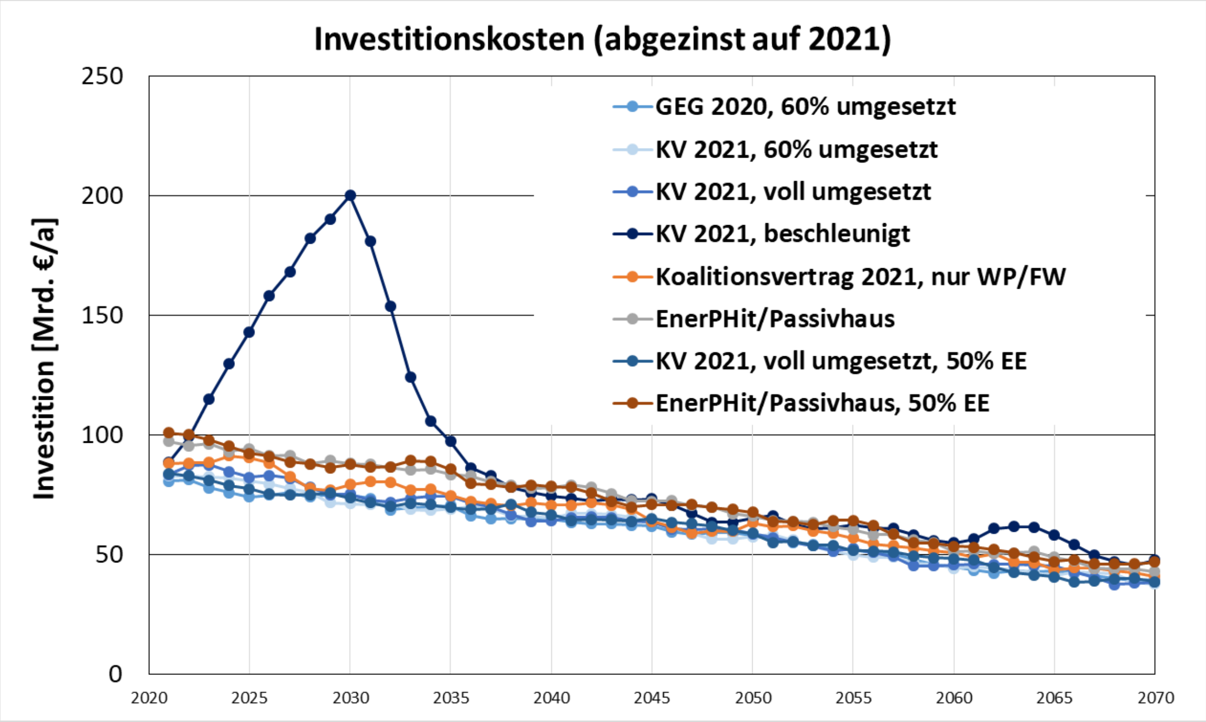


Figure 94: Investment costs for energy-relevant measures in the studied scenarios over time.

6. CONCLUDING SUMMARY

In recent years, there has been increasing concern about the impacts of energy poverty, climate change, and the energy crisis. To address these issues, various countries have been exploring different approaches to reduce energy demand, increase energy efficiency, and promote renewable energy. In this context, several studies and reports have been conducted to evaluate the effectiveness of different energy efficiency measures and renewable energy sources. The DistrictPH examples of these studies show, how increased energy efficiency can tackle aspects of these problems.

In Greece, the study was conducted to evaluate the impact of energy-efficient renovations in a neighborhood. The results showed that by implementing relatively simple interventions following a holistic approach, the energy efficiency of the neighborhood could be significantly improved, with the final energy requirement being about four times lower than the initial situation. Moreover, the interventions resulted in achieving thermal comfort conditions, with the internal temperature limit for the energy calculations being 20.1 ℃ in the final state, while it was 17.1 ℃ in the initial state. With the Passive House Standard in mind, energy efficiency and CO2 emissions could be minimized 3 to 5 times as to the initial situation. In addition, energy poverty in the neighbourhood is eliminated, as heating and cooling costs are negligible.

In Austria, the municipality of St. Johann in Tirol plans to prepare an energy concept for the entire municipal area in the coming year. The districtPH calculation presented by the local district heating company, social housing company, and the University of Innsbruck showed promising results for energy-efficient renovations in the built environment. This suggests that energy-efficient renovations can be effective in reducing energy demand and greenhouse gas emissions in the built environment as well.

Similarly, in Bulgaria, a study was conducted to evaluate the impact of energy-efficient renovations in the district of Golo Bardo and has resulted in significant reductions in energy demand and greenhouse gas emissions. The renovation scenarios examined in this report have shown that by renovating buildings up to National standards, the district has achieved a reduction of 53% in heating demand, while renovation up to EnerPHit standards has resulted in a remarkable reduction of 87% in heating demand, as well as a 54% reduction in CO_2 emissions and 67% reduction in CO_2 emission for the EnerPHit renovation with photovoltaics. These results demonstrate the significant potential of energy-efficient renovations in reducing energy consumption and greenhouse gas emissions in the built environment.

Aside from the direct energy and emissions savings, building renovations also offer several other non-energy benefits. Improved indoor air quality, increased comfort, and reduced noise levels are just a few of the benefits that can result from building renovations. Furthermore, the use of photovoltaics in the district can significantly reduce reliance on grid electricity and promote the use of renewable energy. Although the installation of PV modules and battery storage would only contribute for about 45% of the total electricity consumption, this is still a significant contribution to the district's overall energy mix.

The EnerPHit standard, with its high energy performance requirements, is an effective approach to reducing energy demand and emissions in the built environment. This standard provides a holistic approach to building renovations, ensuring that all aspects of a building's energy use are addressed. Additionally, it provides a clear framework for building performance, making it easier to measure and track energy savings over time.

While the district has made significant progress in reducing energy demand and emissions, it is important to note that net-zero energy status was not achieved. This suggests that further energy efficiency measures or additional renewable energy generation would be required to achieve net-zero energy status. Furthermore, although district heating is a very beneficial approach to reducing emissions, it is not practical or economically viable in the given district due to its small size, low population density and the overall sentiment of Gabrovo's citizens towards district heating. It will be possible if people change their attitude to district heating, but this is a long process involving a generational change and intensive communication at local level.

In summary, the refurbishment of the city district has resulted in significant reductions in energy demand and greenhouse gas emissions, demonstrating the potential of energy-efficient renovations in the built environment. The use of photovoltaics and the EnerPHit standard are effective approaches to reducing energy consumption and promoting renewable energy, while also providing several non-direct benefits. While there is still room for improvement, these results demonstrate the district's commitment to promoting sustainability and reducing its environmental impact.

In Germany, the study was conducted to evaluate the impact of energy efficiency measures and renewable energy sources in achieving the climate protection goals of the Paris Agreement. The results showed that the decisions made in the 2021 German coalition agreement would, in theory, be suitable for advancing toward the climate protection goals of the Paris Agreement. However, consistent implementation of the EnerPHit standard in existing buildings and the Passive House standard in new constructions would be significantly more advantageous, both in terms of greenhouse gas emissions and economically. These approaches offer better resilience and higher flexibility, as well as the possibility of compensating for emissions of individual buildings that are difficult to retrofit.

To achieve these goals, consistent application of the coupling principle and laying down requirements regarding the quality of the building envelope are necessary. In addition, requirements relating solely to primary energy or CO2 are not sufficient, and a heating energy demand based on the living area/useable area should be specified in new constructions. These measures will create a reliable basis for a low energy demand in the first place, promoting energy efficiency and reducing greenhouse gas emissions.

The following guiding principles can therefore be derived from the study, which can contribute to achieving the goals:

a) Consistent application of the coupling principle. If a component is to be renewed, the opportunity must always also be taken to improve efficiency to a sustainable level. Exceptions to the rule for conditional measures should be reduced.

b) Furthermore, requirements must be laid down regarding the quality of the building envelope, e.g. by specifying U-values or maximum values for H'T in the case of the existing building stock. In new constructions, it is better to do this with a heating energy demand based on the living area/useable area. In this way, a reliable basis for a low energy demand will be created in the first place. A requirement relating solely to primary energy or CO2 is by no means sufficient.

c) A higher quality must be implemented – with each retrofit, regardless of the reason for it. Quality assurance similar to that for Passive House certification, supplemented with individual on-site visits/appointments would be helpful here. Adequate CO2 prices which are equally borne by tenants and landlords may have a supportive effect. The coalition agreement has already foreseen cushioning of the social effects of high energy prices. This will be successful, in a sustainable way, especially if the measures are aimed at improving energy efficiency, i.e. if energy consumption is reduced. Subsidizing a high demand and thus continuing to support the fossil energy system with all its implications would be counterproductive.

d) The expansion of renewable energy must be implemented as planned. If this does not succeed, then a higher level of efficiency will be even more crucial. Regardless of exactly how future developments proceed, highly efficient buildings will allow deadlocks to be reliably avoided; they will be a "no-regrets" measure. Above all, they will facilitate the situation even when, in the course of restructuring, shortages in the supply of fossil energy occur e.g. due to political reasons!

e) Heat recovery ventilation and improved airtightness are recommended for reducing loads, particularly in winter. The minimization of loads is important, especially with heat pumps, because investments are decreased due to this, and/or less expensive peak-load electricity is needed. In this way, substantial costs can be saved in especially critical periods in which a lot of heating is necessary but there is little sun and hardly any wind. Investments in network expansion can also be shouldered more easily as a result. Heat pumps should always be dimensioned so that they will still function efficiently in the heating load case.

f) Suitable standards are needed for building efficiency. Assessment of CO2 alone is unsuitable because CO2 is a flexible goal and would lose all relevance as a benchmark when the energy supply becomes completely renewable. This is not appropriate because every form of energy provision implies an ecological cost (in the most favourable case this means additional land use). The efficiency of the building envelope as the most durable component should be evaluated separately; the specific heating energy demand is particularly suitable for this. The load/burden on the future renewable energy system due to the building as a whole, including the heat supply, can be assessed easily on the basis of the PER system, for example.

In the EnerPHit/Passive House scenario described above, just slightly greater renewal rate is sufficient for reducing the heating energy demand of existing building stock within 20 to 30 years by a factor of 2. Due to the coupling principle, this is exceptionally economical – for the most important measures even cheaper than today's heating energy from fossil energy sources. Not only can implementing these measures save energy costs and decrease CO2 emissions to almost zero, but it can also relieve the financial burden on households. In addition, in place of fossil energy from abroad, regional manpower can be deployed for carrying out construction measures. This will create jobs and increase domestic value creation.

Furthermore, such an approach based on the EnerPHit principle will increase public sector revenues – a multiple win-win situations will result.

Nevertheless, this scenario will not run by itself: it requires boundary conditions that must be actively created, which we will detail here once again:

1. Communication: there are many examples of building retrofits to a sustainable level of efficiency. Let's make these better known/let's raise awareness of these! Information initiatives are needed for this; the project documentation available in the Passive House database/portal (https://passivehouse-database.org/) and the international Passive House Open Days are a good basis for this. The focus now is on existing building stock!
2. Implementation to a high standard ("if you do it, do it properly") and – even when rapid action is needed – without impeding further subsequent measures. Capacity of the trades is necessary for this, and (easily communicated) basic training on the topic of "Why is energy efficiency necessary in existing building stock, and how this can be achieved effectively and sustainably?"
3. Advanced training: Let us impart the know-how for energy efficient retrofits. The courses offered by the PHI are a good basis for this: https://cms.passivehouse.com/de/training/kurse/.
4. Let's help the industry to quickly adapt their production of building components to energy efficient components. Good examples are available with the certified Passive House components – small and large companies have already successfully mastered this transition; it's not as hard as some people think. The Passive House Institute provides advice to companies in this connection. Passive House suitable components are documented in the component database: www.componentdatabase.org.
5. The financial resources must be made available: for this, what matters above all is the willingness of banks to preferentially finance such retrofit measures as well. Interest rates are low at present, investment projects are actually being sought – these are good prerequisites. However, in many cases banks are often hesitant when it comes to measures that serve climate protection because often, realistic rather than speculative expected returns are stated here – which, when considered from this perspective, is an advantage.
6. Public funding of measures must be directed towards overcoming dependency on fossil energy sources: saving CO2 as well as ensuring that climate neutrality can be achieved consistently with these forms of assistance. For this reason, systems that continue to rely on fossil energy sources as a "bridging" technology" must not receive funding, and neither should incentives be provided for low quality retrofits such as those without improved ventilation, or such as those in which double glazing or uninsulated window frames are again used etc. Instead, based on the results of the scenarios, special incentives should be set for highly energy efficient deep retrofits.

Sustainable building stock will follow almost automatically from a programme which leads to the use of highly efficient components with competent planning and expert implementation.

Anything other than that would not be an adequate contribution to climate protection – on the contrary, it would fix the bad state in place over further decades (lock-in effect). In summary, the studies conducted in Greece, Austria, Bulgaria, and Germany show that increased energy efficiency is the key to addressing energy poverty, reducing greenhouse gas emissions, and getting one step closer to climate targets set by the Paris agreement.

7. APPENDIXES

7.1. APPENDIX A

Basic structure of districtPH

For reasons of flexibility and transparency, districtPH was released as an Excel spreadsheet. Building-related energy consumption and the effects of refurbishment measures play a central part. Furthermore, districtPH considers user-related energy consumptions in buildings which are supplemented by street lighting and the energy consumption of trams and other electric vehicles. A district heating system and the electricity grid, including short and long-term storages, can be represented. Estimation methods for the energy production from renewable sources were included as well.

For some parts algorithms from the [PHPP] could easily be integrated, while many other methods were developed from scratch. We assumed that the data acquisition would not be as accurate as when planning a new building. Design drawings will not be available, neither will exact component qualities, numbers of inhabitants, etc. as it would lead in unnecessary computing cost. Once accepted, this fact allows for entering the buildings in the districtPH by assigning them to certain pre-defined building types from a typology.

One of the major goals in the development of districtPH was the prediction of how the district's energy demand evolves over time. Since future developments will always depend on many currently unknown parameters, the calculation results will have an unavoidable inaccuracy, which in turn justifies time-saving simplifications of the calculation methods themselves. The resulting inaccuracies are only of minor importance for practical purposes: What is relevant for decision-making are the advantages of certain strategies in comparison to others, not so much exact predictions of the energy consumption in absolute figures.

The first step in setting up an energy balance is to enter the buildings in the districtPH. Each building is assigned to one of up to 30 building types, which can be either user-defined or chosen from the Episcope database [Tabula 2018]. The buildings with their type, their positions and square meters of floor area can be entered. The building types already contain efficiency levels for all building components and the mechanical systems.

Excel can now calculate the energy balance of each building type with regard to heating, cooling, hot water, and electricity, and report the sum totals of e.g. delivered energy, CO2 emissions, or source energy. The relevant results are saved, and the districtPH moves on to the next year. Now, with a user-defined probability, a retrofit of the building components to a different efficiency level takes place, and the calculation process starts again.

In order to deal with the exponentially growing number of buildings from year to year, a Monte Carlo method was selected: The number of building types remains constant in every time steps, with each building type having only one renovation status, determined by retrofit probabilities. The whole simulation is repeated several times, with different random numbers, until the average of all individual results for the required quantity has been determined with sufficient accuracy.

This core calculation process is supplemented by several additional tools:

- An import filter from the PHPP, for defining a building type from existing PHPP input data
- A variant management, allowing for a comparison of e.g. different supply structures
- An economics calculator, suitable to determine economically optimal renovation measures
- A climate data worksheet, where local climate data can be entered
- A set of worksheets for an hourly analysis of electricity and district heating networks

Building Model

Parameters of the building structure

Several different considerations influenced the decision on the structure of building model data.

- It should be possible to set up a model for a whole district in a short time. Input of the buildings and building types should be simple and fast.
- The available data will usually not be very detailed. Construction drawings will not be available.
- To allow for a comparison of refurbishment scenarios, many buildings need to be calculated over many years in many variants, multiple times. The calculation model has to be extremely fast.
- Buildings have to be aggregated to building types, with a certain inevitable loss of accuracy.

It becomes clear that only simple models could be used in districtPH as the computational cost is of great importance. Even the input for a PHPP calculation would be inappropriate, let alone the additional detail for a dynamic simulation.

The building types' description is therefore limited to the following information:

- building age class
- treated floor area
- number of storeys
- number of dwelling units
- area and U-value of 2 roof types, 3 wall types, 2 floor types, 1 entrance door type
- area of 5 windows, horizontal and facing the four cardinal points
- U-value and g-value of windows
- thermal bridge supplement
- airtightness, characterized by the blower door result n50
- efficiency of heat recovery, if an
- temperature set points for heating and cooling (only for non-residential buildings)
- number of persons (only for non-residential buildings)
- internal heat gains (only for non-residential buildings)

This level of detail is sufficient to calculate the useful energy demand for heating and cooling, both for residential and non-residential buildings.

Heating

The model for calculating the heating demand is based on a monthly energy balance according to [EN ISO 13790]: Month by month, heat losses at the temperature setpoint are calculated. Internal and solar heat gains are multiplied by a utilisation factor and then subtracted from the heat losses. The remainder needs to be supplied by the heating system.

This methodology has proven it's validity in a large number of certified Passive Houses. For buildings with a lower energy standard, the temperature setpoint needs to be modified (cf. section 3.4). The heating worksheet from the PHPP was used as a basis for the calculation.

Cooling

If an active cooling system is installed in the building, the cooling demand is calculated following a similar procedure as for the heating demand. Again, the temperature setpoint depends on the insulation level.

Any possible dehumidification demand is calculated alongside the cooling demand.

Realistic calculation of heating demand

For residential buildings, following the methodology described in [Schnieders 2018], an effective room temperature setpoint is determined depending on the insulation level. This temperature accounts for partial heating both of different rooms and at different times, as well as for other influences that were found in the comparison of measurements with energy balance calculations.

Non-residential buildings, e.g. indoor swimming pools or storage facilities, can have different levels of temperature. For these buildings the heating and cooling temperature setpoints need to be added as part of the building type description in the typology.

Domestic hot water (DHW)

The useful energy for DHW production is assumed to be 25L per person per day at 60 °C for residential buildings. In non-residential buildings, this value is reduced to 5L.

Mechanical systems

Mechanical systems are implemented with a similar level of detail and accuracy as the building envelope. The following data are required for every building:

- energy carriers and total system efficiency, separately for heating, DHW, and cooling
- efficiency level of use of other electricity, e.g. for domestic appliances in residential buildings
- for non-residential buildings, a reference electricity demand is required as an additional input
- utilisation profile for heating, DHW, and electricity

Different systems are directly represented by different efficiencies, with default values being provided for the most important system types. Electrical heating, for example, can mean that an electrical resistance heater is installed (efficiency 100%), but it can also refer to an air-source heat pump (efficiency 200 - 300%) or a ground-source heat pump (efficiency 300 - 500%). Drain water heat recovery can be represented by an improved efficiency of the DHW system, etc.

Auxiliary electricity

Auxiliary electricity is mainly required for circulation pumps, but also e.g. for fans, control systems, defrosting or crankcase heaters. The fraction of auxiliary electricity, as part of the total useful energy produced, can be close to negligible, like in modern high-quality hydronic heating systems. However, it can also make up a fraction of 5% in older heating systems, let alone systems like absorption chillers. Therefore, a fraction of auxiliary electricity is assigned to every heating, cooling, or DHW system.

Auxiliary electricity consumption of solar domestic hot water systems is also considered, using a fraction of 5% of the useful heat produced.

For ventilation systems with heat recovery it is assumed that the electricity demand is correlated with the thermal efficiency, with high-efficiency ventilation units having more efficient fans as well. An indicative correlation is following.

P_el=1.25 Wh/m^3 (1-η_(heat recovery))V

Efficiency levels

In order to allow for a comparison of refurbishment strategies and the resulting energy consumption it is necessary to find an abstract description of these strategies in the following chapters. For this purpose, it turned out to be appropriate to group the efficiency levels of building components into classes. We chose a pattern with 9 groups which are numbered from 1 (usually the worst standard) to 9 (usually the best). The following table shows an example:

EFFICIENCY CLASSES FOR WALL ASSEMBLIES									
CLASS NUMBER	1	2	3	4	5	6	7	8	9
U-VALUE ($W/(m^2K)$	4	2	1.5	1	0.6	0.3	0.2	0.15	0.1

This type of group assignment applies to the components of the building envelope, such as walls, roofs, windows, as well as to the mechanical systems. It is not necessary to follow the exact procedure from 1 to 9 and the U-Values can be changed from the user.

Renewable energy production

Renewable energy can be produced on the building in different variations. The following options are available in districtPH:

- no renewables
- solar thermal for DHW only
- PV only
- solar thermal for DHW + PV
- solar thermal for DHW and heating
- solar thermal for DHW, with excess heat provided for district heating
- solar thermal for DHW and heating, with excess heat provided for district heating

The energy yield of these systems is calculated building by building, but, for reasons of simple use, without further user input. The following assumptions are made: Solar thermal collectors and PV modules have a default inclination towards the equator, and only a default fraction of the gross roof area is available for renewables. There are no additional heat losses from the solar DHW storage because, although the solar storage may be bigger than the conventional storage it replaces, it will usually have a better insulation. Solar hot water is produced with a standard flat plate collector, and modules made from monocrystalline silicon provide photovoltaic electricity.

If only DHW is produced, no more than 1.5m² of collector area per person is assumed. If heating support is chosen, the fraction of the roof which is available for renewables is fully dedicated to this purpose. Whatever part of the roof's available fraction is not required for solar thermal can be used for PV.

Concerning the roof area that is available for solar energy use, default factors were determined according to the following considerations: For Germany, deviations from the optimum orientation by up to ±75° or, alternatively, from the optimum inclination by up to ±35° reduce the solar radiation sums by less than 10%. A few experiments using the f-chart method for calculating the yield of solar thermal systems resulted in the following conclusions:

- A similar relation holds for the solar thermal energy production, depending on the orientation, as it does for the solar radiation sums.
- For flat roofs, it may be assumed that the whole roof is available for solar energy, except for roof windows, anchorage points, ventilation units, skylights, the areas of roof parapets, etc.
- For a saddle roof with the two roof areas pointing north and south, only one of the roof areas will be used. Because of the more favorable orientation and the larger total roof area, the solar gains are still 60 to 80% of the gains on the horizontal roof.
- If the two roof areas face east and west, both roof areas are likely to be used. In this case, the yield would even be higher than on a flat roof, by 10 to 20%, albeit at higher investment cost.

It may be concluded that the amount of solar energy that can be harvested on a roof mainly depends on the horizontally projected area. With acceptable accuracy, the actual shape of the roofs is not required for the calculations in districtPH.

[UBA 2010], in a careful estimate, assumes that 25% of the total roof area receive sufficient solar radiation for PV installations to be feasible, with 70% of that area actually being available (due to chimneys, installations, etc.). In [Gertec 2008], 40% of the horizontally projected roof area are considered suitable for solar energy use, with solar radiation sums above 1000kWh/(m²a).

As a default value in districtPH, 50% of the building's footprint area are assumed to be available for a horizontally oriented solar collector or PV installation. 30% are deducted from this area for skylights, chimneys, etc. The default shading factor for these installations is 0.9.

Evolution over time

One of the major goals in the development of districtPH was to provide a means for investigating the evolution of a district over time. The renovation rate of different building components depends on political boundary conditions, the economic situation, legal requirements, the age and status of the building stock, etc. In any case only a (usually small) fraction of the buildings of a certain building type will be refurbished in a particular year. A suitable methodology to deal with this situation needed to be developed.

Not Suitable: Calculating every building by itself

In principle, the calculation could be carried out separately for every building in the district, using its specific geometry, mechanical services, building components, and use. Usually, such an approach would be far too time-consuming; gathering the required information and setting up a suitable energy balance may be expected to take more than one day's work per building.

Not Suitable: Precalculating all combinations

It is convenient, both in terms of data acquisition and calculation times, to assign every building to a building type of a typology. The probability of component refurbishments to a certain efficiency level is then considered for each building type. A possible algorithm that reduces the required calculation time to a minimum can be described as follows: Every component of the building is assigned to one of a limited number of efficiency levels, as described in section 3.8. Each individual building's state is then described by a set of efficiency levels for all of its components. The finite number of combinations allows for a pre-calculation of the energy consumption for every combination, which could be done without further user interaction. Afterwards, depending on the probability of refurbishment, only the (not necessarily whole) number of buildings of a specific component combination changes. One big advantage of this approach is that refurbishment probabilities can be considered, but the calculation result is determinate nevertheless. Unfortunately, it turned out that the number of possible combinations becomes very big: If 10 building types with 10 possible states for wall, roof, floor, window, and ventilation, and 10 variants of the mechanical services for heating and DHW are considered, this already results in 10(1+5+2) = 106 combinations. Any additional building parameter would again multiply the number of variants by 10. The requirements for calculation capacity and storage would thus quickly become very inadequate.

Monte Carlo Method

Based on the above considerations a so-called Monte Carlo method was chosen for the investigation of scenarios: Only one instance of each building type is considered. The change of its status from year to year, based on the refurbishment probabilities, is observed and the results of interest are recorded. If this procedure is repeated sufficiently often, the average of all results represents the expected value of the result sufficiently well. The standard deviation of this average can easily be calculated from the results of each Monte Carlo run. It is therefore possible to adjust the number of runs to the desired accuracy of the result or to the required selectivity in cases where different scenarios are to be compared.

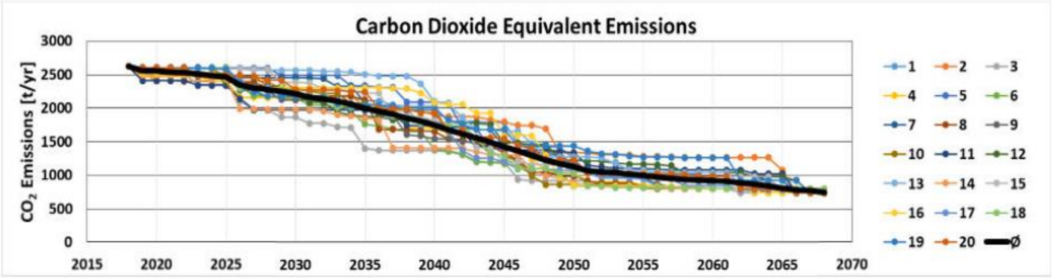


Figure 1: 20 different monte carlo runs for the co2 emissions in a refurbishment scenario. The thick black line represents the average of 100 runs.

Probabilities for refurbishment

From the above it is clear that each component (roof, wall, windows, heating system, etc.) has a certain probability of being refurbished to a certain efficiency level at the end of the year that is currently considered in the simulation. This probability depends on the age and, often to a lesser degree, on the efficiency level of the component. For simplicity, districtPH divides this probability into two parts:

- Will there be any renovation of the component at all?
- If so, which will be the new efficiency level?

For the first question, it appeared appropriate to allow for a probability distribution, too. The Weibull distribution, which is zero for negative arguments, appeared appropriate. Its two parameters can roughly be correlated with the average lifetime of the component and with the spread around this average. These data can be entered by the user.

The implementation starts from the cumulative distribution function. It gives the probability that a component has been renovated at least once after n years. Figure 2 shows a typical example.

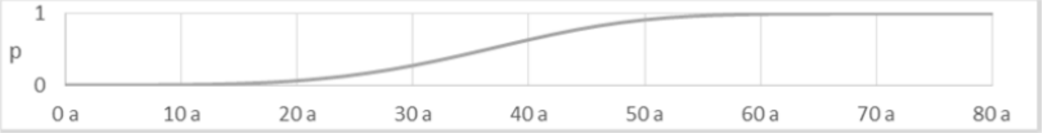


Figure 2: Cumulative Weibull distribution function for an average lifetime of 50 years and a spread of 12.5 years. The curve shows the probability p that at least one renovation has taken place after the specified time.

Since there can be only one renovation per year in the model it is necessary to discretise the distribution function. Let pk(n) be the value of the cumulative distribution function at an age n, and p(n) the probability of a renovation at the age n. Then pk(n) is a sum of two probabilities: that the component has been renovated before the year n, and that it is renovated in the year n but has not been renovated before. Thus

pk(n) = pk(n-1) + (1-pk(n-1))p(n)

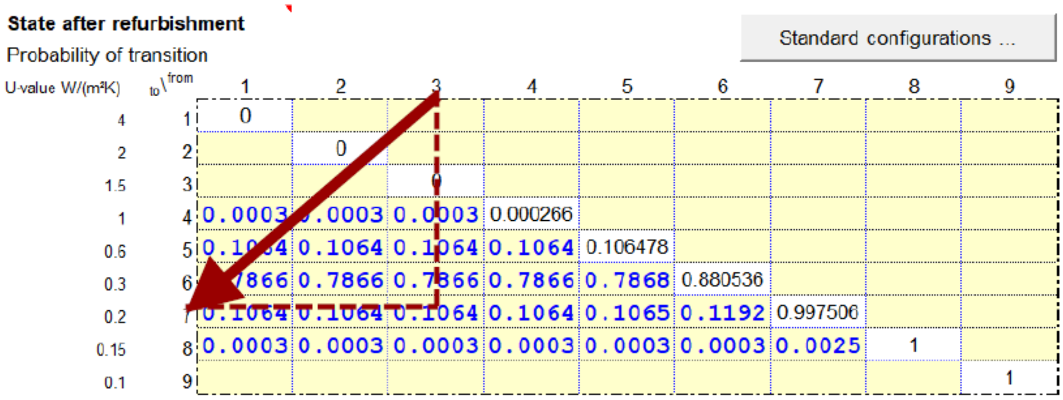
By rearranging this equation, p(n) can be found as a function of the cumulative distribution.

Mind that p(n) is not the probability density function. The latter, when integrated over a certain period of time, relates to the probability that a newly installed component will be renovated during this period. The calculation, on the other hand, requires the probability that a certain component is renovated in the current year if no renovation took place before. This latter probability increases from year to year, whereas the probability density function always declines after a certain point in time.

The second question, concerning the new efficiency level, is answered by an additional probability matrix. Figure 3 shows an example: If the wall has an efficiency level of 3, equivalent to a U-value of 1.5 W/(m²K), the probability that its efficiency level will change to 7 (U-value 0.2 W/(m²K)) is 10.64%

– If a renovation takes place at all.

It may also happen that a renovation does take place because the lifetime of the component is reached, but that no improvement to the efficiency level takes place. This is reflected by a non-zero value in the main diagonal of the probability matrix. In such a case, only the age of the component is reset to the current year.



State after refurbishment

Probability of transition

U-value W/(m²K)	to\from	1	2	3	4	5	6	7	8	9
4	1	0								
2	2		0							
1.5	3			0						
1	4	0.0003	0.0003	0.0003	0.000266					
0.6	5	0.1064	0.1064	0.1064	0.1064	0.106478				
0.3	6	0.7866	0.7866	0.7866	0.7866	0.7868	0.880536			
0.2	7	0.1064	0.1064	0.1064	0.1064	0.1065	0.1192	0.997506		
0.15	8	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0025	1	
0.1	9									1

Figure 3: The probability of a transition from one level to another can be found from the probability matrix.

Energy Supply

In order to reduce the emissions produced for the heating of the building and the electricity we have to terminate the usage of fossil fuels, such as oil for heating and to turn towards a more green way of electricity production. So this section deals with the production of heat and electricity in their respective networks and, in particular, with methodologies of assessing different types of heat and electricity generation.

Assessment

There are several options to assess the structure and amounts of energy consumption and production in a district. Examples include:

- Primary energy demand: the energy that needs to be provided at the beginning of the energy conversion chain to provide a specific service, including all losses and auxiliary energy demands during this process. Often renewable and non-renewable primary energy are distinguished.
- CO2 equivalent emissions: Carbon dioxide is the most important greenhouse gas. The warming effects of other emissions, e.g. methane or synthetic refrigerants, can be measured in CO2 equivalents. Burning biomass would usually not be considered to produce CO2 because the carbon in the biomass has previously been removed from the atmosphere. In the following, like in districtPH, the abbreviated term 'CO2 emissions' is used.
- Primary Energy Renewable: This assessment method compares different types of energy use for a fully renewable energy supply. It was developed by the Passive House Institute.
- Zero energy / energy autarky: A zero energy district would not require any energy to be imported. A more precise definition is required when energy autarky is only achieved to a certain degree, and different types of energy must be balanced.
- Net zero energy: Over the course of the year, the amount of energy produced in the district at least matches the amount of energy consumed. Often only electricity is involved in this balance. An important property of this benchmark is that energy production and consumption need not occur simultaneously; the grid is assumed to be an ideal storage. If necessary, a primary energy reference can be used to compare different energy carriers.

The results of the districtPH balance contain a breakdown of the useful, delivered, and primary energy demand of the district, including PER and CO2 balances. Electricity imports and exports as well as possibly missing heat supply for the district heating system are summarised, too. The Excel table allows for arbitrary other benchmarks to be implemented by the user.

Calculation Model

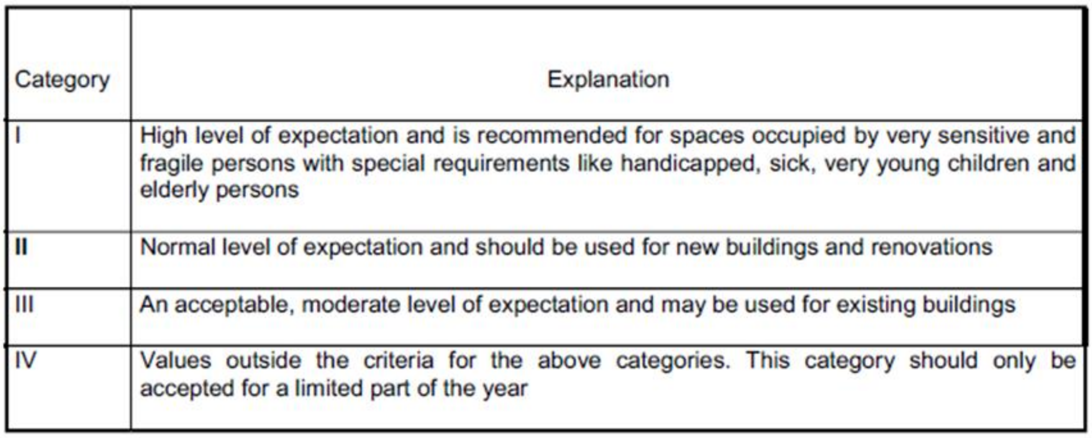
For the multiple calculations of scenarios over several decades, a fast, sufficiently accurate calculation method was required. The method had to be able to determine the fraction of the total heat load that is covered by each heat generator. It also had to be able to take short and long-term storages into account. An hourly analysis was implemented to allow for detailed investigations and for comparison with simplified methods, but was carefully kept separated from the rest of the calculation model to allow for easy removal. As expected, this type of model requires unacceptably long calculation times when applied to long-term scenarios, but it can be useful for more detailed investigations of a specific state of the district. Since the load on a district heating system depends on the weather and varies from month to month, attempts were made with a model similar to the well-proven monthly heating and cooling energy balance of EN ISO 13790. It appeared promising to treat heat gains from renewable sources, waste heat, etc. analogously to solar and internal heat gains in a building model, and to determine the fraction of this heat that can be utilised by the district via a utilisation factor based on the ratio of gains to losses and on the time constant. However, the utilisation factor was difficult to determine in general, particularly since no relationship between the time constant and the network properties could be identified. Finding adequate models for heat storages, with their non-linear behavior, was an additional challenge for this monthly approach. Finally, a method was developed that works with representative weeks, separately for winter and summer. Loads and heat supply capacities are chosen in a way that results in correct averages over the heating and cooling period, respectively. Possible mismatches of loads and capacities as well as the load shift potential of e.g. storages are represented correctly by using typical hour-by-hour profiles. The hourly analysis also allows to consider the fluctuating nature of renewable energy sources. To account for the effects of offices and schools that are closed on weekends, for waste heat that is only available during working days, etc., there are three types of days in each season: Monday to Friday, Saturday, and Sunday. On this basis, the load, including network and storage losses, is distributed to the different heat generators. Obviously, such an approach is less accurate during extremely cold or hot periods, on mild spring or autumn days, or around Christmas and Easter. Nevertheless, comparisons with hourly calculations – that neglect special holidays as well – resulted in an acceptable agreement.

7.2. APPENDIX B

Thermal Comfort

Thermal comfort is that condition of mind that expresses the feeling of satisfaction or discomfort according to the thermal environment. Because there are individual variations in terms of physiological, psychological, social, and cultural nature, or even from person to person, it is difficult to measure in an objective way a person’s satisfaction in a space. Extensive laboratory and field data have been collected, that provide the necessary statistical data to define conditions that a specified percentage of occupants will find thermally comfortable [ANSI/ASHRAE 2010]. There are several factors that affect thermal comfort which can be divided into two main categories, the personal and the environmental factors. According to the ASHRAE Standard 55, the six primary factors that contribute to a person’s thermal comfort are the metabolic rate and clothing insulation – personal factors – and the air temperature, the radiant temperature, the airspeed, and the humidity – measurable environmental factors.

EN 15251 Standard provides a categorization of the indoor environment, moreover thermal criteria are specified correspondingly. The four categories (Cat. I, Cat. II, Cat. III, Cat. IV) are used to describe the level of comfort that must be guaranteed (Table 6). The buildings of the neighbourhood would be considered to fall under Category III in their existing condition. However, after the refurbishment, the comfort levels that should be guaranteed would be the ones determined by Category II, which is used for new or renovated buildings.



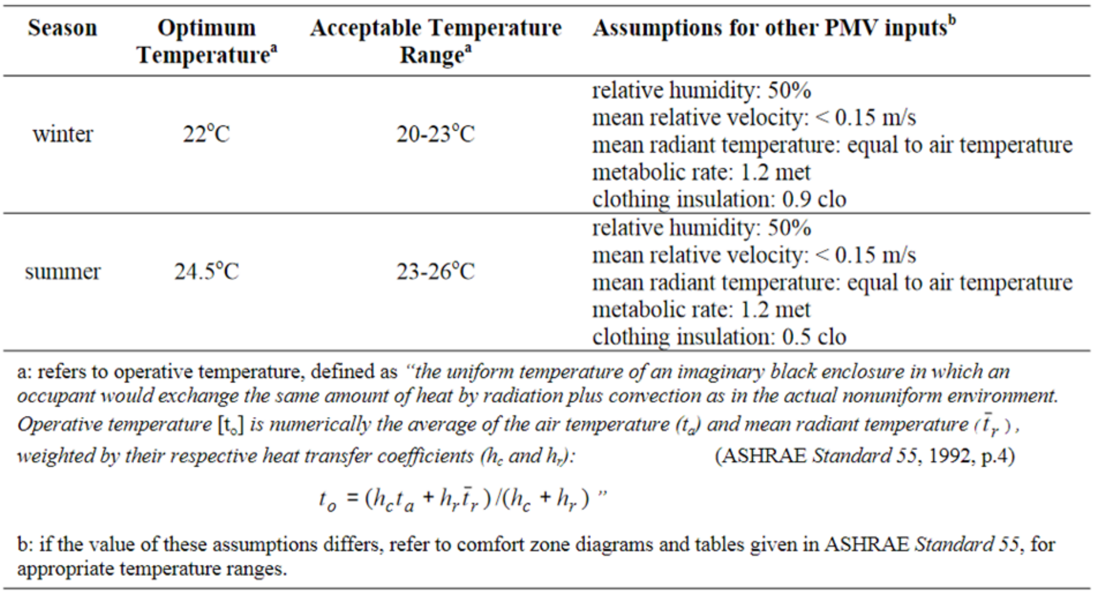
Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III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

Table 6: Description of the applicability of the categories of level of thermal comfort required [EN 15251: 2007]

According to the EN 15251 Standard, the acceptable ranges of indoor temperatures depend on the type of the system used to provide comfort to the building. Based on the type of system (mechanically heated and or/cooled or not) and the comfort category, a corresponding comfort temperature interval is established.

The determination of comfort temperature and thus the evaluation of the long-term comfort levels are correlated with the type of system that provides cooling and/or heating. Assuming that an active system is used, the indoor temperature must respect the limits defined by the static model developed by P. O. Fanger. The static (PMV/PPD) model was developed based on heat balance equations and empirical studies about skin temperature to define comfort. This method does not take into account the adaption of the occupants to outdoor environmental conditions. According to the EN ISO 7730:2005 Standard, the predicted mean vote (PMV) is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale, based on the heat balance of the human body [EN ISO 7730 2005].

PMV may be calculated for different combinations of physical variables (air temperature and velocity, relative humidity and mean radiant temperature) and personal variables (clothing insulation and activity level). The complexity of the PMV index led Fanger in 1970 to create a table that determines the appropriate thermal conditions. The information that this table provides was adapted also not only to modern comfort standards such as the ASHRAE, 1992: ISO, 1994 but also to programs that were developed to calculate the PMV based on the ISO 7730 Standard. These thermal conditions can be seen in the following table and ensure that at least 90 % of the occupants are thermally satisfied [Charles 2003].



Season	Optimum Temperature[a]	Acceptable Temperature Range[a]	Assumptions for other PMV inputs[b]
winter	22°C	20-23°C	relative humidity: 50% mean relative velocity: < 0.15 m/s mean radiant temperature: equal to air temperature metabolic rate: 1.2 met clothing insulation: 0.9 clo
summer	24.5°C	23-26°C	relative humidity: 50% mean relative velocity: < 0.15 m/s mean radiant temperature: equal to air temperature metabolic rate: 1.2 met clothing insulation: 0.5 clo

a: refers to operative temperature, defined as *"the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment. Operative temperature* [t_o] *is numerically the average of the air temperature* (t_a) *and mean radiant temperature* ($\bar{t}_r$), *weighted by their respective heat transfer coefficients* (h_c *and* h_r): (ASHRAE *Standard 55*, 1992, p.4)

$$t_o = (h_c t_a + h_r \bar{t}_r)/(h_c + h_r) \text{ ''}$$

b: if the value of these assumptions differs, refer to comfort zone diagrams and tables given in ASHRAE *Standard 55*, for appropriate temperature ranges.

Table 7: Thermal comfort conditions – ASHRAE Standard 55 (1992) [Charles 2003]

Specific temperature ranges for every thermal comfort category are also provided by the EN 15251 Standard, for the periods when heating and cooling is required. The temperature ranges, for the previously mentioned periods, for residential buildings are presented in Table 8.

Type of building or space	**Category**	**Temperature range for heating, °C** **Clothing ~1.0 clo**	**Temperature range for cooling, °C** **Clothing ~0.5 clo**
Residential buildings, living spaces (bedrooms, living rooms etc.) **Sedentary activity ~ 1.2 met**	I	21.0 – 25.0	23.5 – 25.5
	II	20.0 – 25.0	23.0 – 26.0
	III	18.0 – 25.0	22.0 – 27.0

Table 8: Temperature ranges for hourly calculation of cooling and heating energy [EN 15251: 2007]

As mentioned in Section 3.4, the setpoint room temperature, both for the heating and the cooling case, is determined based on the insulation level of the buildings. The results of the setpoint temperatures according to districtPH are summarized in Table 9.

District Condition	Category	Setpoint room temperature for the heating period [°C]	Setpoint room temperature for the cooling period [°C]

Existing condition	III	17.1	28.1
Refurbished	II	20	25

Table 9: Setpoint room temperatures of according to insulation level

As it can be seen from the tables above, after the refurbishment, the expected internal temperature in the buildings respects the limits set by the EN 15251 Standard for renovated buildings and therefore thermal comfort is guaranteed to the users of the buildings. On the contrary, it is clear that the setpoint temperature in the buildings in their existing condition is outside the range determined by the Standard and it can be expected for the users to feel thermally unsatisfied during both the heating and the cooling period. It must be mentioned that the determination of the final energy demand of buildings should be complemented with a thermal comfort analysis. as the energy demand solely cannot provide sufficient data in terms of the overall efficiency of a building.

Based on the results of this particular study, it can be concluded that not only the final energy demand of the buildings on their existing condition is very high but also users would still be thermally unsatisfied.

7.3. APPENDIX C

Variations

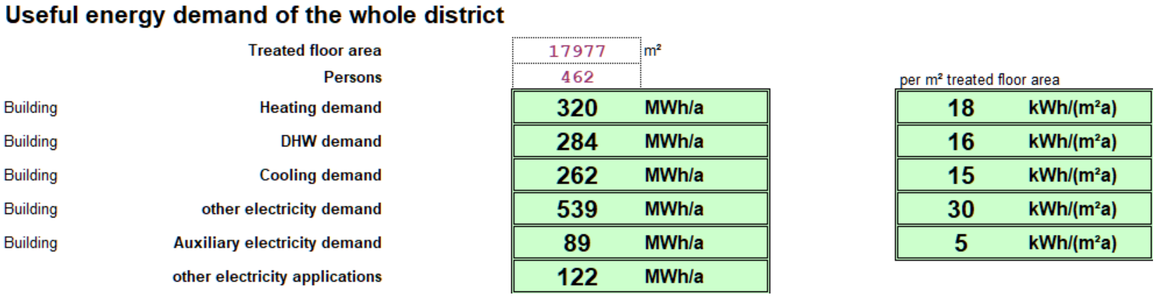
Energy reduction in the building sector is crucial for the mitigation of climate change and for the creation of more sustainable and environmentally friendly urban areas. Buildings are a strategic focus of the European Union, since the large amount of the existing old and energetically inefficient building stock is also a major source of air pollution. Moreover,

Airtightness

As it was stated in Section 7.2.1., ensuring an airtight envelope of a building is one of the five basic principles of the Passive House concept. Airtightness is a refurbishment measure that is both cost-effective and has a substantial influence on the energy efficiency of the building. Typical building systems in Greece are constructed with concrete and brick-plaster materials which ensure airtightness. Infiltration is then only possible through cracks and windows but can be easily prevented if proper building components, such as seals and adhesive tapes, are used

In order to quantify the impact of the airtightness level of the building on the final energy demand, an alternative simulation has been performed. All the other parameters of the refurbished neighbourhood are kept identical to the ones mentioned in Chapter 7, however the airtightness level is assumed to be equal to the one of the initial state.

The results of this simulation are demonstrated on the table below:



Useful energy demand of the whole district

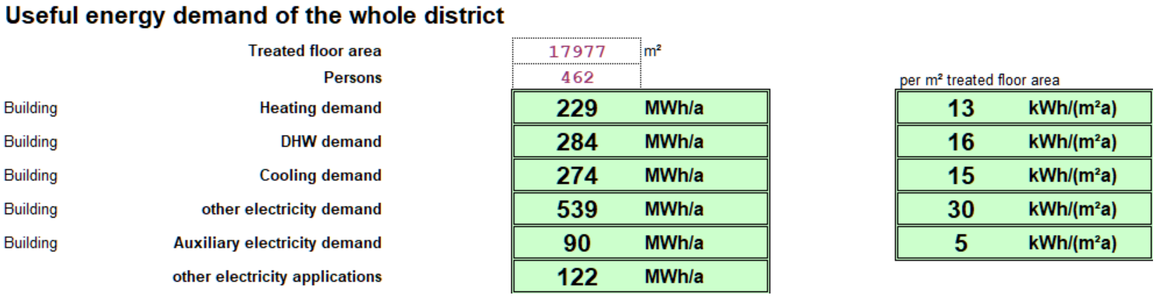
	Treated floor area	17977	m²		
	Persons	462		per m² treated floor area	
Building	Heating demand	320	MWh/a	18	kWh/(m²a)
Building	DHW demand	284	MWh/a	16	kWh/(m²a)
Building	Cooling demand	262	MWh/a	15	kWh/(m²a)
Building	other electricity demand	539	MWh/a	30	kWh/(m²a)
Building	Auxiliary electricity demand	89	MWh/a	5	kWh/(m²a)
	other electricity applications	122	MWh/a		

It is clear that the impact of the airtightness cannot be neglected as a double fold increase of the final energy demand can be identified. This reveals the importance and the cost effectiveness of such a measure in refurbishment projects.

7.4. APPENDIX D

One of the biggest advantages of refurbishment projects in whole districts is that they are constituted of terraced buildings. This feasibility study, performed with districtPH shows that it is cost efficient to refurbish districts with this characteristic rather than individual buildings. An area of 4 260,6m^2 of external walls should be insulated and approximately 783,8m^2 of windows should be installed. For these windows 199,1m^2 will be on the northern side, 195,5m^2 in the southern side and 389,2m^2 in eastern and western in total.

Another alternative simulation was performed in which all the sides of the buildings were assumed to be exposed to the external environment. This means that the heat losses, which were not taken into consideration previously between adjacent buildings, are now calculated. The results of this simulation can be seen on the table below:



Useful energy demand of the whole district

	Treated floor area	17977	m²		
	Persons	462		per m² treated floor area	
Building	Heating demand	229	MWh/a	13	kWh/(m²a)
Building	DHW demand	284	MWh/a	16	kWh/(m²a)
Building	Cooling demand	274	MWh/a	15	kWh/(m²a)
Building	other electricity demand	539	MWh/a	30	kWh/(m²a)
Building	Auxiliary electricity demand	90	MWh/a	5	kWh/(m²a)
	other electricity applications	122	MWh/a		

As can be seen from the table, based on the results of this simulation, the increase of the final energy demand is almost 50% compared to the results of the refurbished district. This result can lead to the conclusion that such refurbishment projects are especially beneficial in high density neighborhoods which are typical mainly in the city center of Athens.

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