Erasmus+ Project ID: 2023-1-ES01-KA220-HED-000156652

This Erasmus+ Project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the European Commission and Erasmus+ National Agencies cannot be held responsible for any use which may be made of the information contained therein

Romanian Case Study

Part I: Romanian Case Study approach and analysis of the building initial situation

1. Case study approach

The Romanian case study focuses on an educational building. It involves the analysis of energy demand and consumption, as well as the proposal of alternatives to enhance the energy efficiency of the building.

2. Description of the educational building

2.1. Introduction

The Romanian case study is a primary and lower secondary school, built in 1962 and located in Petrindu/Cuzăplac village, Sălaj County, Romania (see Fig. 1 and 2.).

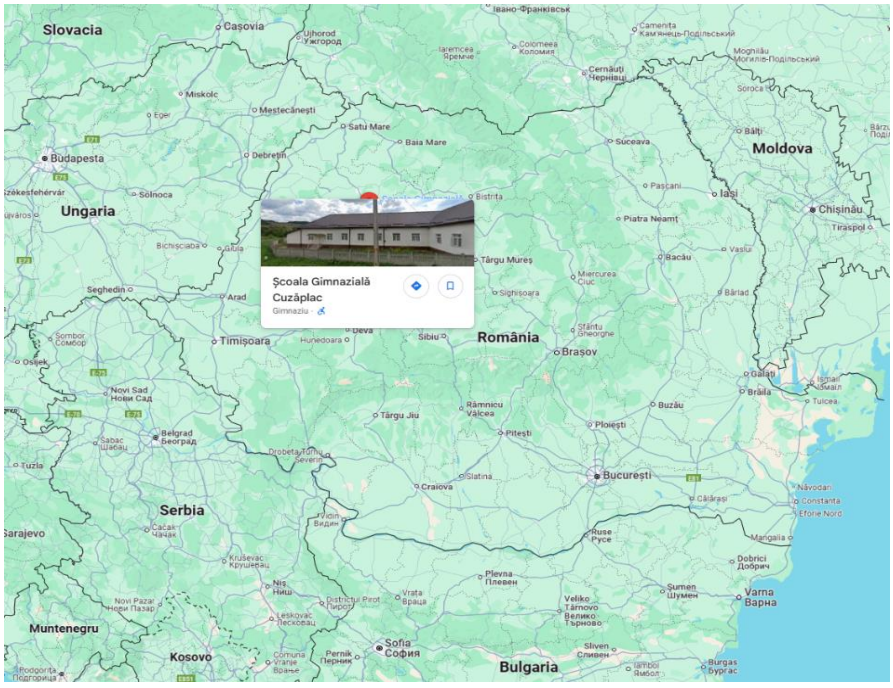
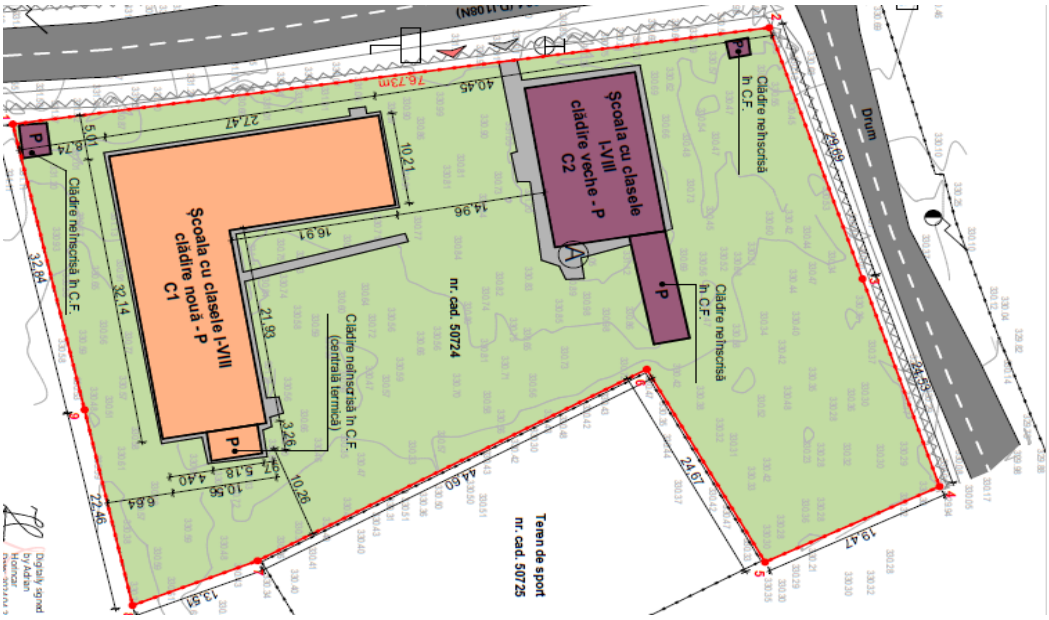


Figure 1. School from Romania – map location

Figure 2. School from Romania – pictures

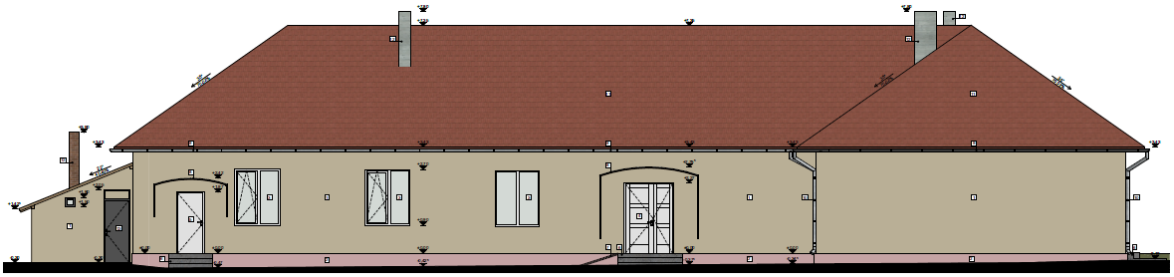
2.2. Building Plans

The total area of the land is 3861 sqm (see Fig. 3).



3. **Figure 3.** School from Romania – situation plan

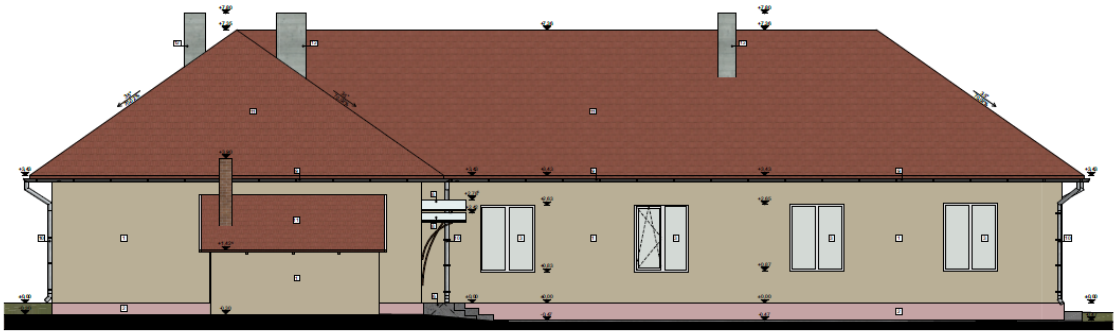
The building (C1) has one ground floor and a total built area of 512 square metres, with a total useful area of 413.8 square metres (see Fig. 4).



North

West

South



East

Figure 4. School from Romania – facades

The building comprises 3 classrooms, 1 kindergarten room, two hallways, a teaching materials storage, an office, three storage rooms, a toilet and a technical room (see Fig. 5).

The cold-water supply is from the local network. The building is heated by a solid fuel thermal plant and a boiler, which are connected to steel radiators. The lighting system is made up mostly of neon fluorescent tubes. The building doesn't have a ventilation or air conditioning system.

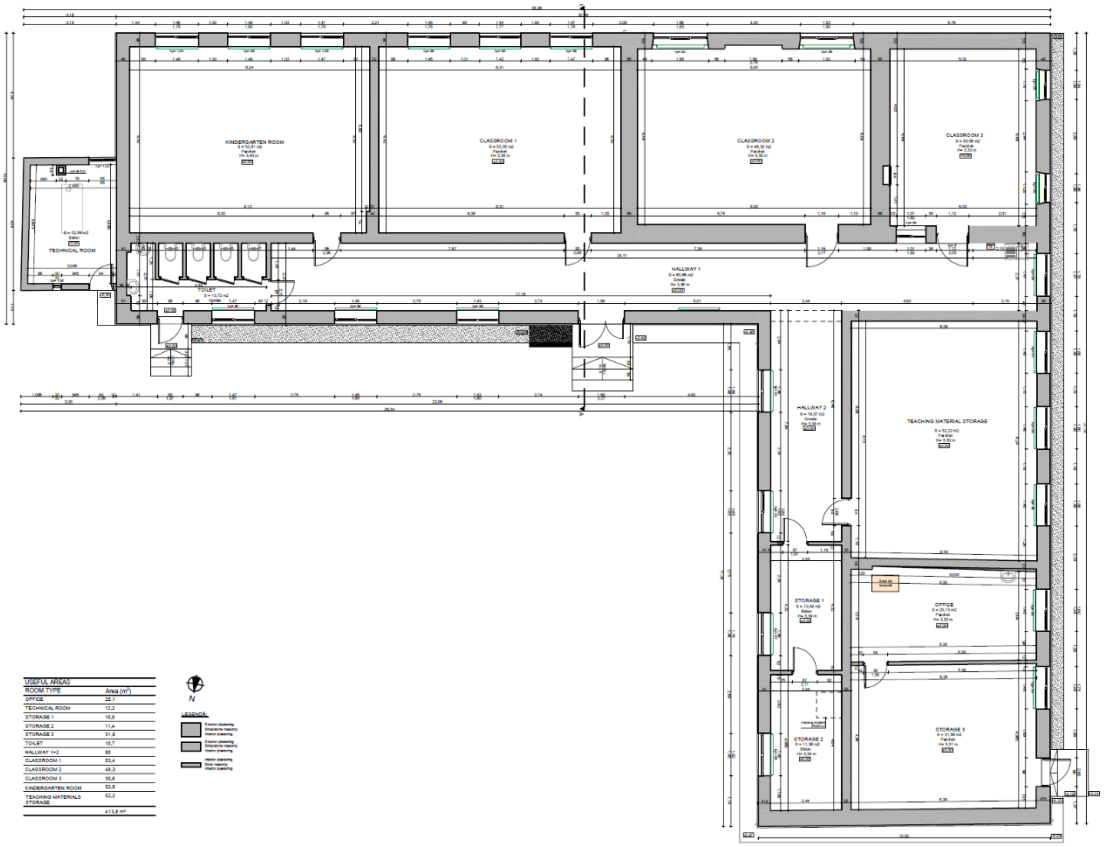


Figure 5. School from Romania – ground floor plan

2.3. Location

The geographical coordinates of this building are:

- Latitude: 46°57'56"N
- Longitude: 23°11'24"E
- Elevation: 293.2m

Location data		
City	Cuzaplac	
Altitude	293.200	m
Latitude	46.0	degrees
Longitude	23.0	degrees
Time zone	2.0	
SCOP climatic conditions	Cold climate	

2.4. Climatic zone

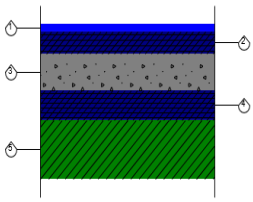
According to the Koeppen-Geiger classification system, Romania is characterized by six distinct climate types. The predominant climate zone is a humid continental climate with warm summers (Dfb), which encompasses the largest area of the country (including the building area for our case study). During the warmest month of the year, the average temperature does not exceed 22°C. In contrast, the average temperatures during the coldest month are typically much lower, often significantly below −3°C.

2.5. Thermal Envelope Materials

The building has a stone and concrete structure, brick walls, a wooden attic floor and a wooden roof with bituminous corrugated boards. The interior walls were finished with washable paint or tiles, while the exterior was enhanced with decorative plastering. Concrete floors are covered with parquet or tiles. The building is not insulated. The windows have PVC frames and double glazing.

The following data were used in this case study:

Floor slab



List of layers:

1	-Ceramic/porcelain	2.00 cm
2	Cement-, sand	6.00 cm
3	Concrete-. Reinforced (with 1% steel)	10.00 cm
4	Cement-, sand	8.00 cm
5	-Sand and gravel (density 1700)	16.00 cm

Characteristics

Thermal transmittance, U: 0.85 W/(m²-K)
Total thickness 42.00 cm
Characteristic length, B': 2,204 m
Thermal resistance of the slab, Rf: 0.28 (m²-K)/W Slab surface, A: 82.21 m²
Perimeter of slab, P: 74.593 m Thermal conductivity, λ: 2,000 W/(m-K)

Roof

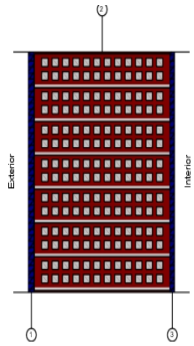
List of layers:

1	- Wood (density 500)	2.00 cm
2	- Wood (density 500)	23.00 cm
3	- Wood (density 500)	2.00 cm
4	- Lime, sand	1.50 cm

Characteristics

Thermal transmittance, U: 0.45 W/(m²-K)
Total thickness 28.50 cm

External wall 45

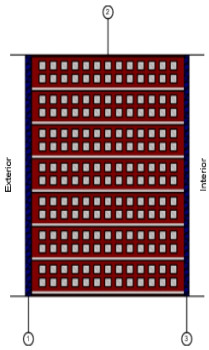


List of layers:

1	-Lime, sand	2.00 cm
2	- Brick M01 - 100mm	45.00 cm
3	-Lime, sand	1.50 cm

Characteristics — Thermal transmittance, U: 1.38 W/(m²-K)
Total thickness 48.50 cm

External wall 50

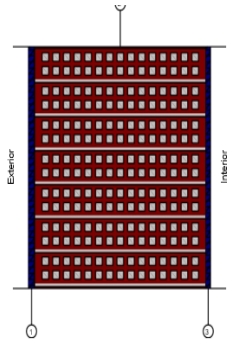


List of layers:

1	-Lime, sand	2.00 cm
2	- Brick M01 - 100mm	50.00 cm
3	-Lime, sand	1.50 cm

Characteristics — Thermal transmittance, U: 1.27 W/(m²-K)
Total thickness 53.50 cm

External wall 55

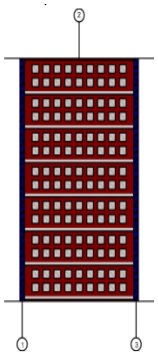


List of layers:

1	-Lime, sand	2.00 cm
2	-Triple LH plank Large Format 100 mm < E < 110 mm	55.00 cm
3	-Lime, sand	1.50 cm

Characteristics — Thermal transmittance, U: 1.19 W/(m²-K)
Total thickness 58.50 cm

Partition wall 35

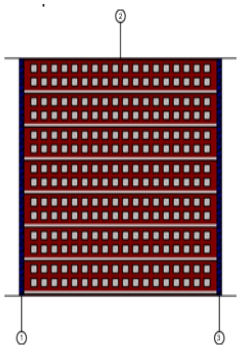


List of layers:

1	-Lime, sand	1.50 cm
2	- Brick M01 - 100mm	35.00 cm
3	-Lime, sand	1.50 cm

Characteristics Thermal transmittance, U: 1.45 W/(m²-K)
Total thickness 38.00 cm

Partition wall 65



List of layers:

1	-Lime, sand	1.50 cm
2	- Brick M01 - 100mm	65.00 cm
3	-Lime, sand	1.50 cm

Characteristics Thermal transmittance, U: 0.98 W/(m²-K)
Total thickness 68.00 cm

Doors

Heat transfer coefficient (U)	2.10	W/(m²·K)
Absorptance	0.60	

Windows

Heat transfer coefficient (U)	2.10	W/(m²·K)
Solar heat gain coefficient	0.70	

2.6. Domestic hot water, heating and air conditioning systems

The water is heated by a thermal plant that uses biomass as fuel. The wood-fired plant isn't very efficient.

The building is heated by steel radiators using a solid fuel heating plant (wood) and a boiler.

There's no ventilation or air conditioning system in the building either.

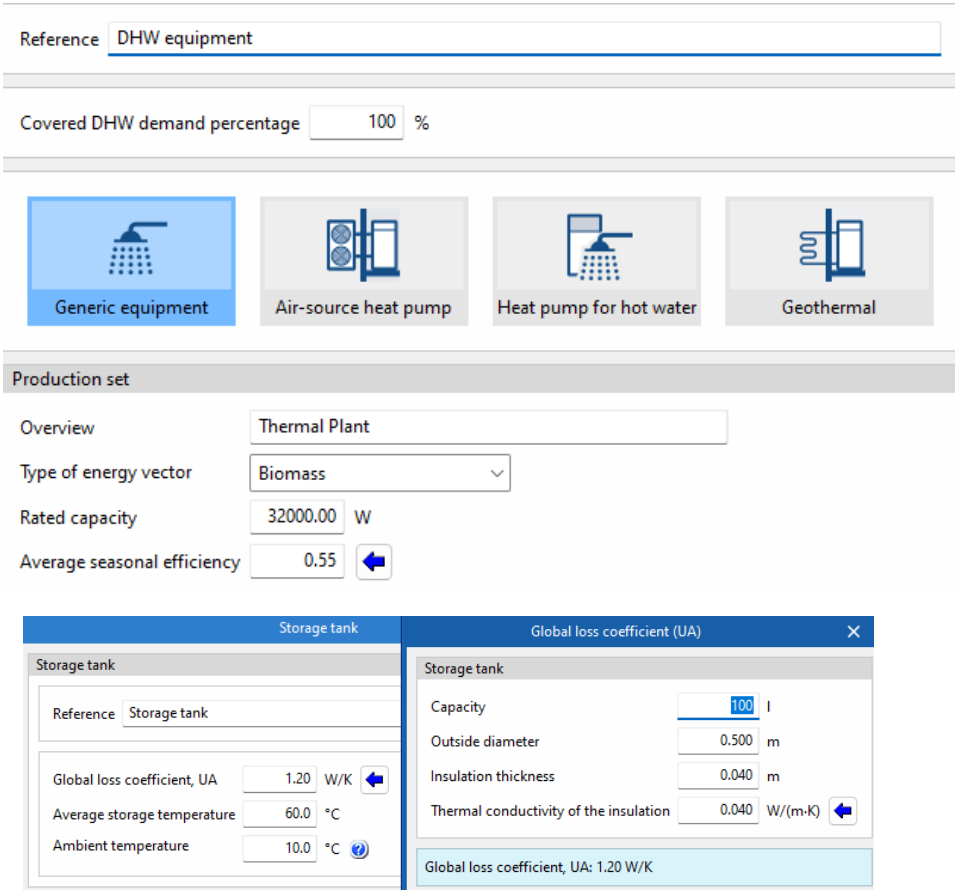


Figure 6. DHW system

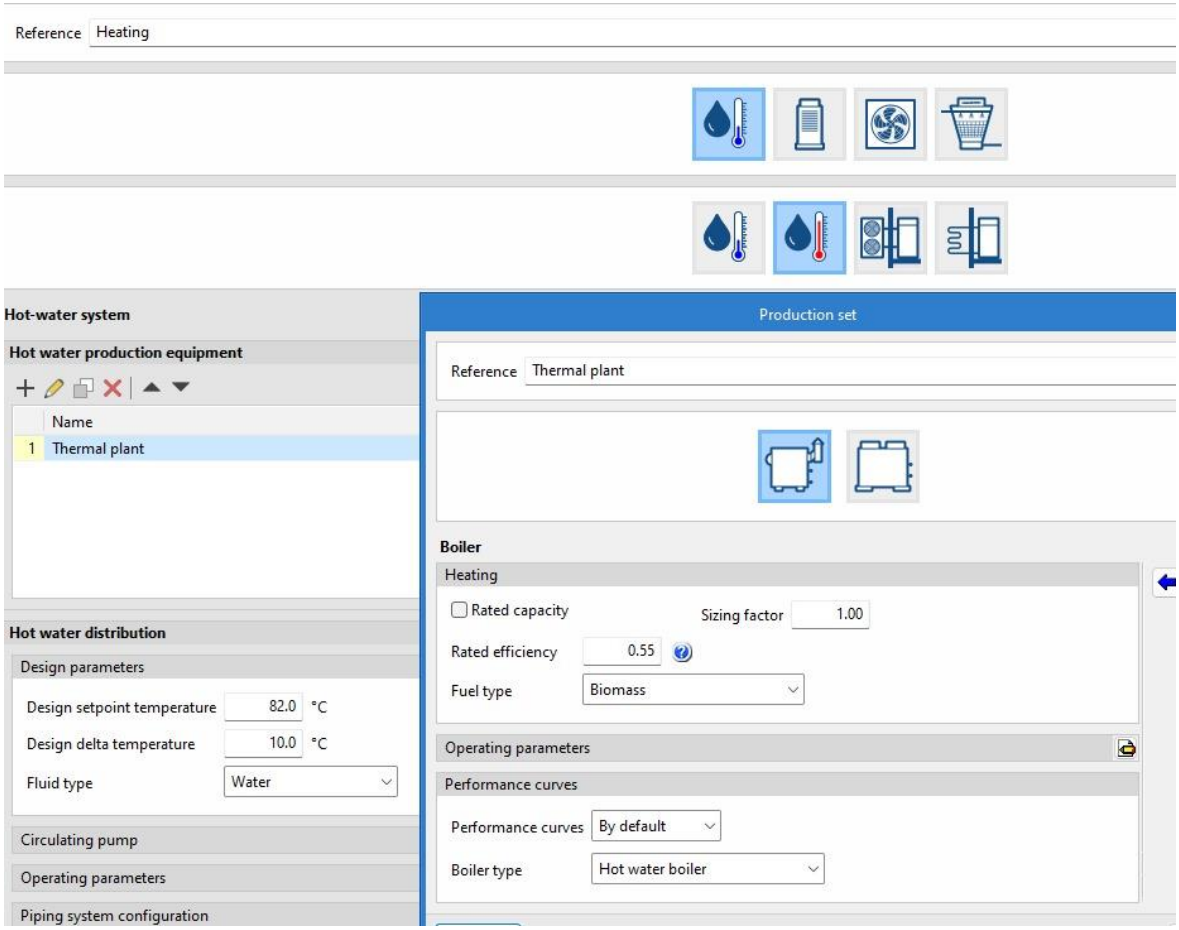


Figure 7. Heating system

3. Development of the Romanian educational building Case Study

3.1. Building BIM model

A Building Information Model (BIM) for energy analysis is a digital representation of a building that integrates both geometric and semantic data, enabling detailed simulations of the building's energy performance. Unlike a standard 3D model, a BIM includes information about materials, thermal properties, occupancy schedules, lighting systems, HVAC equipment, and more.

When used for energy analysis, the BIM serves as a data-rich foundation that can be exported to energy simulation software (EnergyPlus in this case study). This allows energy consultants to evaluate heating and cooling loads, daylighting, thermal comfort, and overall energy consumption.

Key benefits include:

• Automated data transfer from design to simulation

• Improved accuracy due to consistent and detailed inputs

• Integrated design workflows between architects, engineers, and energy analysts

The following figures show several views of the building's geometric BIM model.

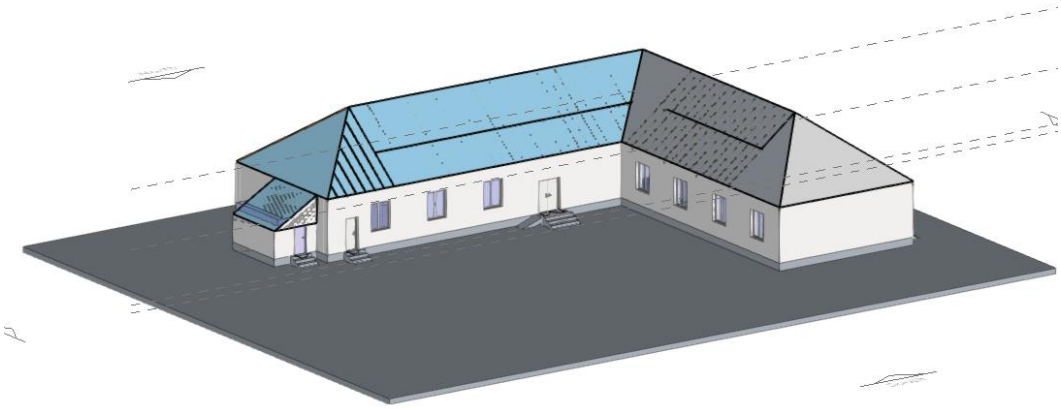


Figure 8. BIM model

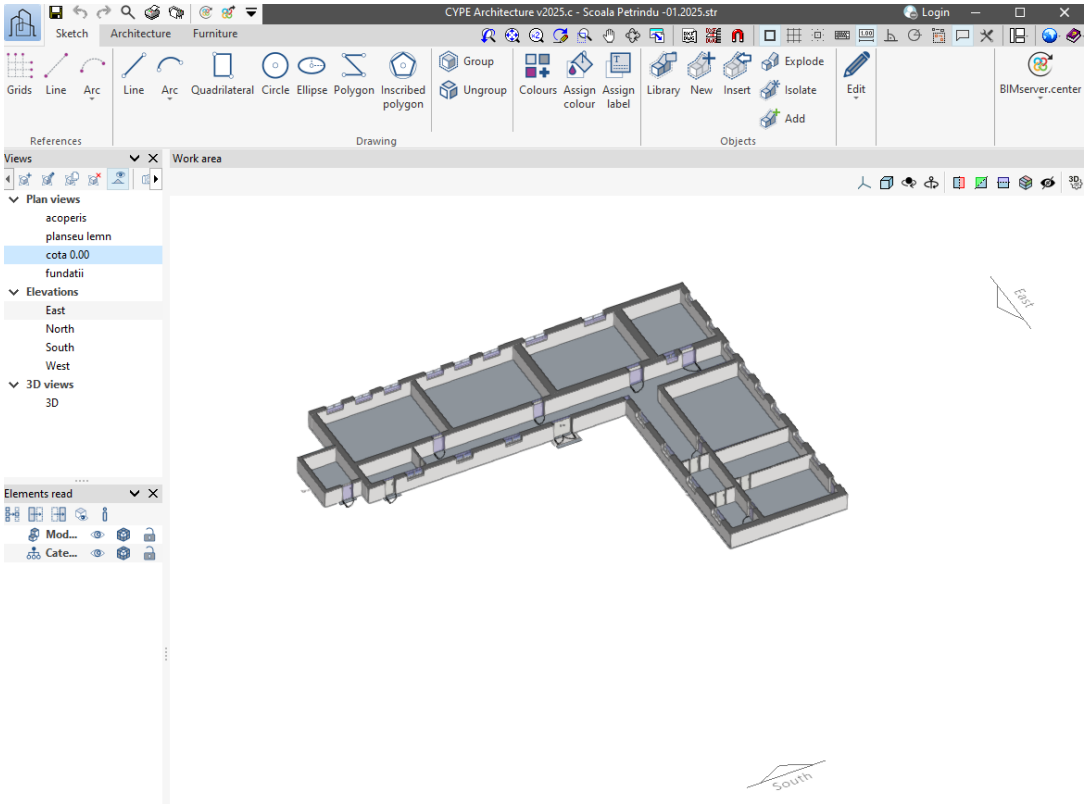


Figure 9. School plan in BIM model

3.2. Building BIM model

The analytical model of the building is made up of the interior spaces of the building into which the interior volume of the building is divided with its characteristics (volume of space, surfaces that eliminate the space...).

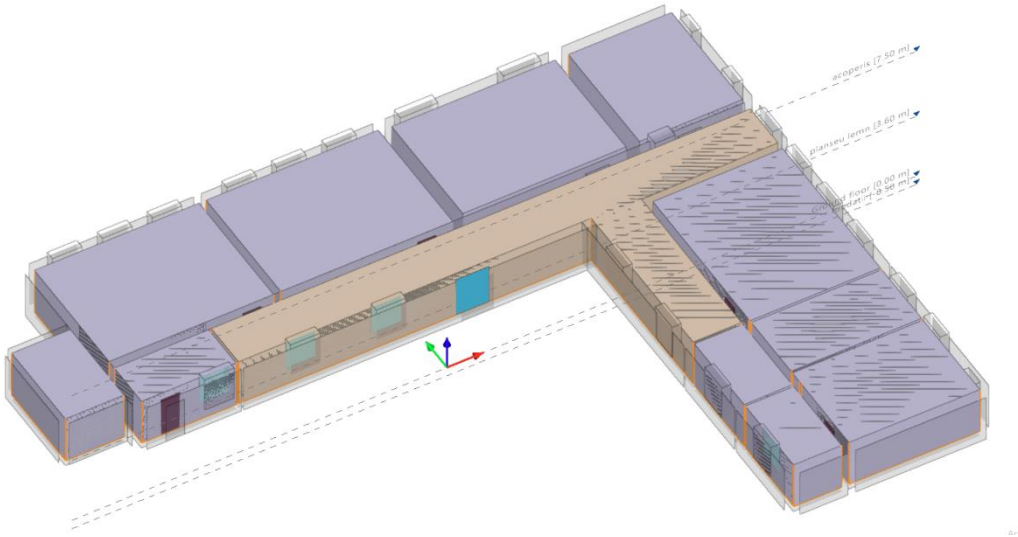


Figure 10. Analytical model of the building

In this work, the interior spaces of the building have been grouped into 2 different zones.

These zones are:

Ground floor is the conditioned area of the building.

Common zone is not habitable area.

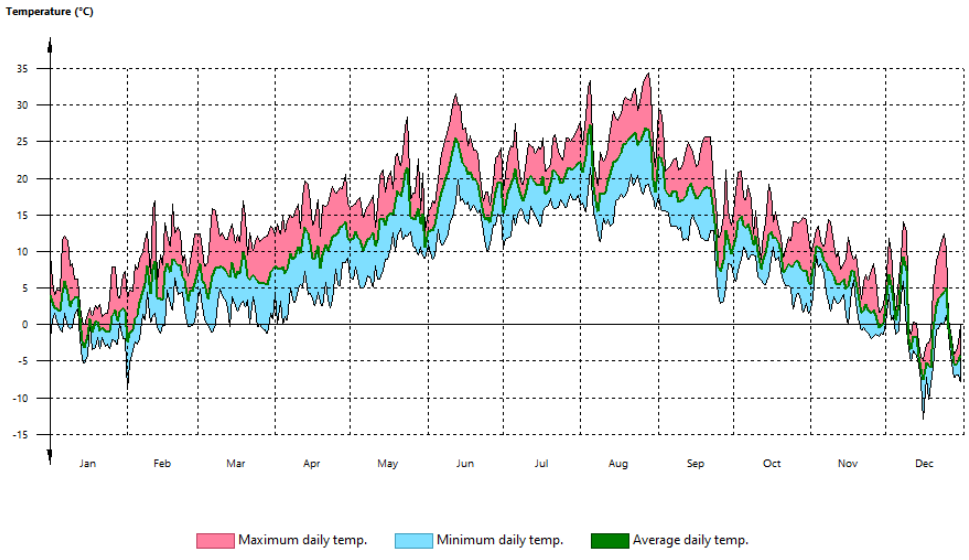
The ventilation of the existing building consists of natural ventilation.

The ventilation needs introduced in the model have been **0.63 interior air renovations per hour** for dwellings, common areas, and kitchens and bathrooms.

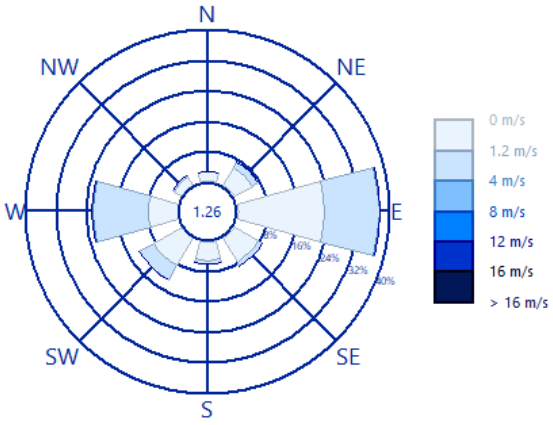
3.3. Climatic zone

The following data were used in this case study:

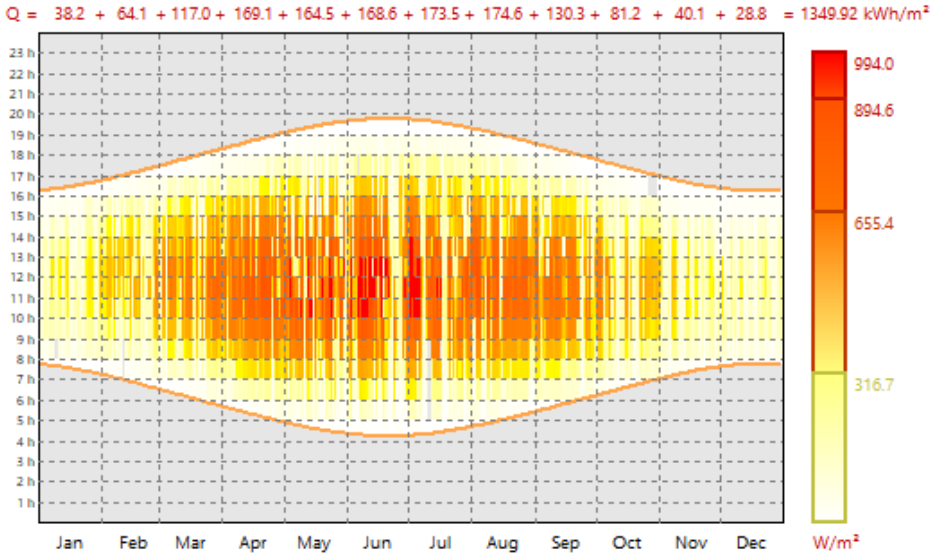
Outdoor temperatures



Wind distribution



Global irradiance on a horizontal surface



3.4. Operational conditions of conditioned spaces for the building

For the energy analysis of the building, the operational conditions of the conditioned spaces of the building have been used, considering a typical school schedule from 8 to 16, from Monday to Friday.

3.5. Building Energy Model

A building energy model is a detailed digital simulation of a building's energy use, created to analyse and predict its energy performance. It includes inputs such as the building's geometry, orientation, construction materials, insulation levels, HVAC systems, lighting, occupancy patterns, and local climate data. The model uses this information to calculate energy consumption for heating, cooling, lighting, ventilation, and plug loads over time.

This model is essential for:

• Evaluating design alternatives

- Estimating energy savings
- Complying with building codes
- Supporting green building certifications (e.g., LEED, BREEAM)
- Performing cost-benefit analysis of energy efficiency measures

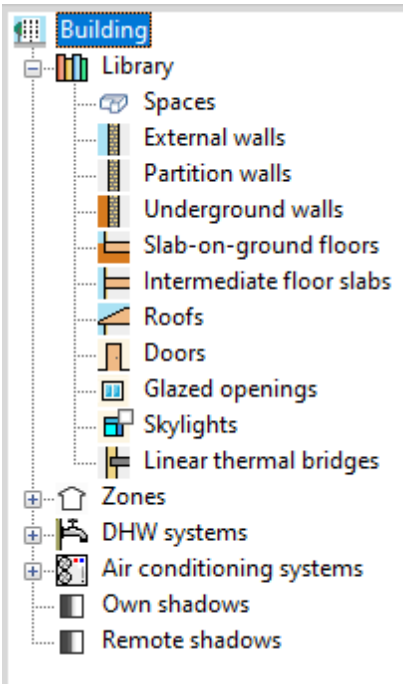
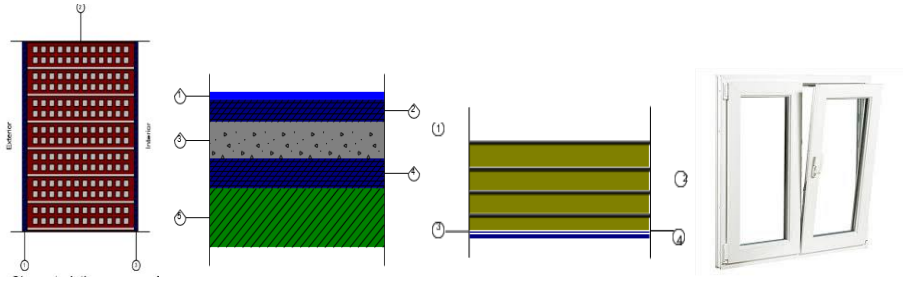
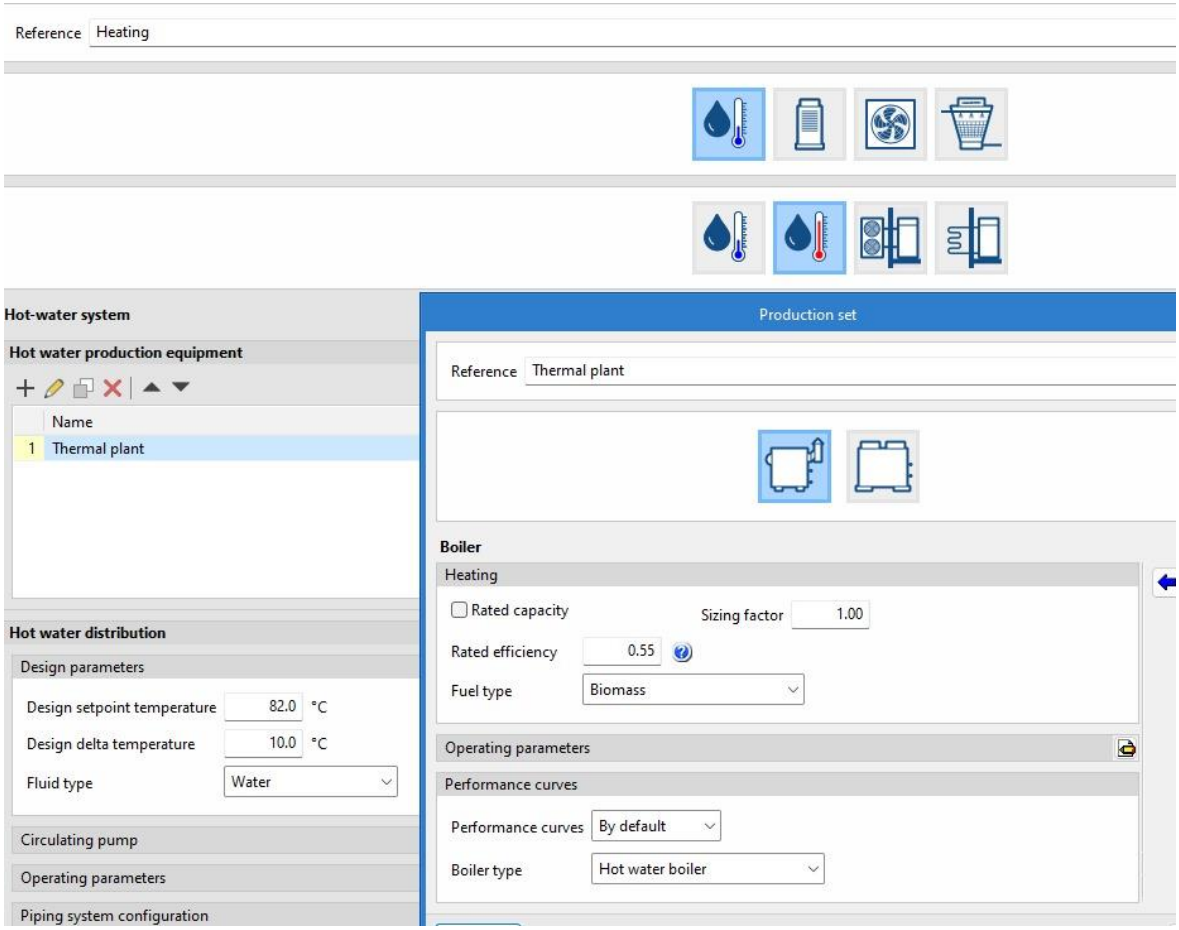


Figure 11. Some components of the Building Energy Model

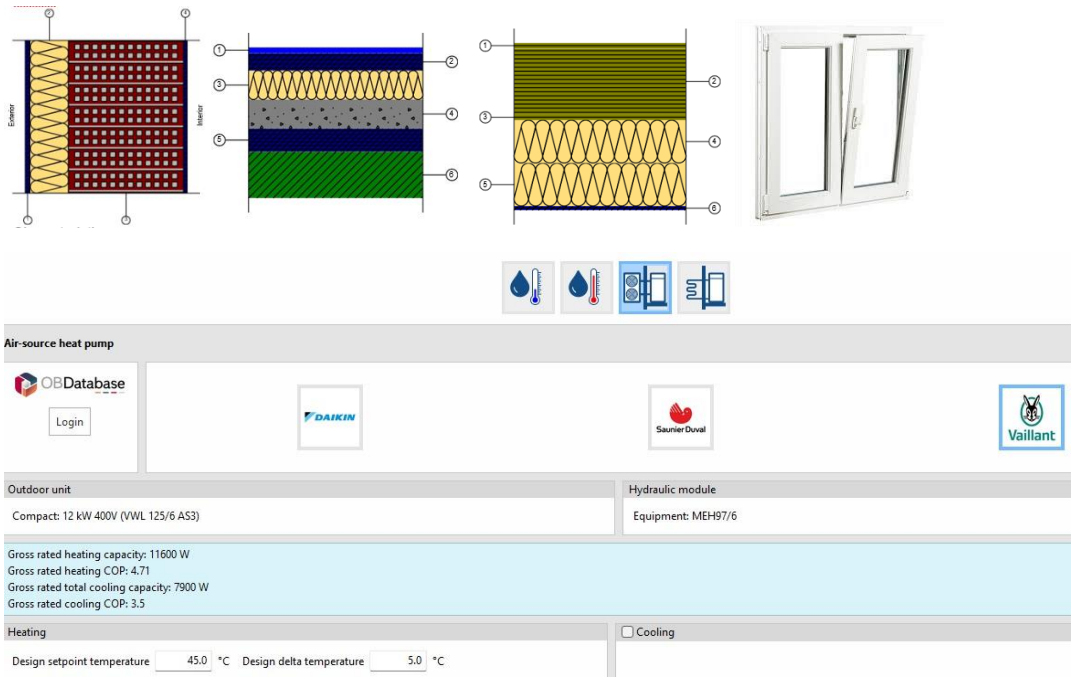
3.6. Cases analysed. Description

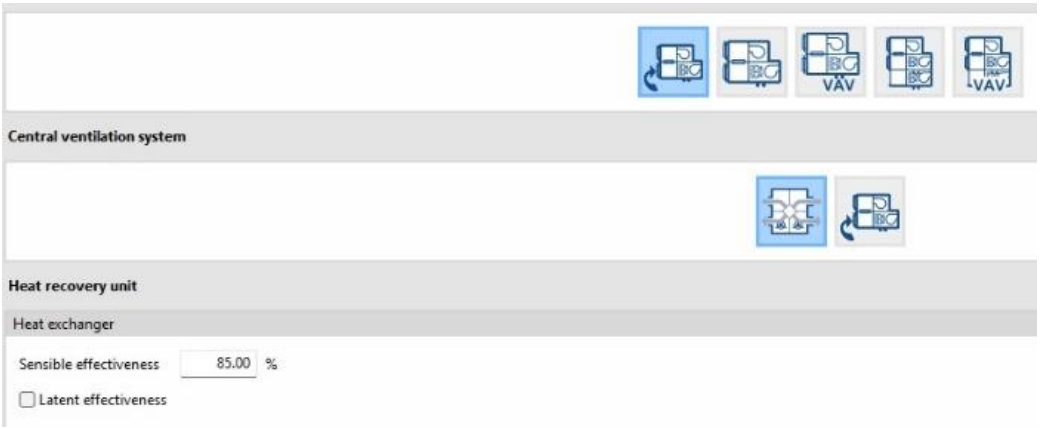
- Case 0: Existing/initial scenario: envelope without insulation, double glazing windows (U=2.1 W/m^{2}K), solid fuel thermal plant (wood) of low efficiency, radiators



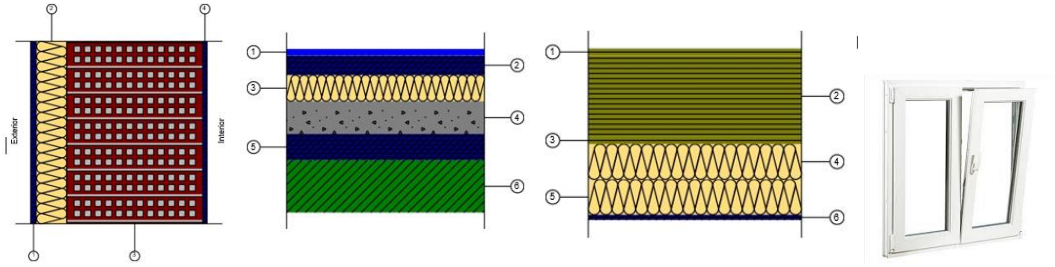


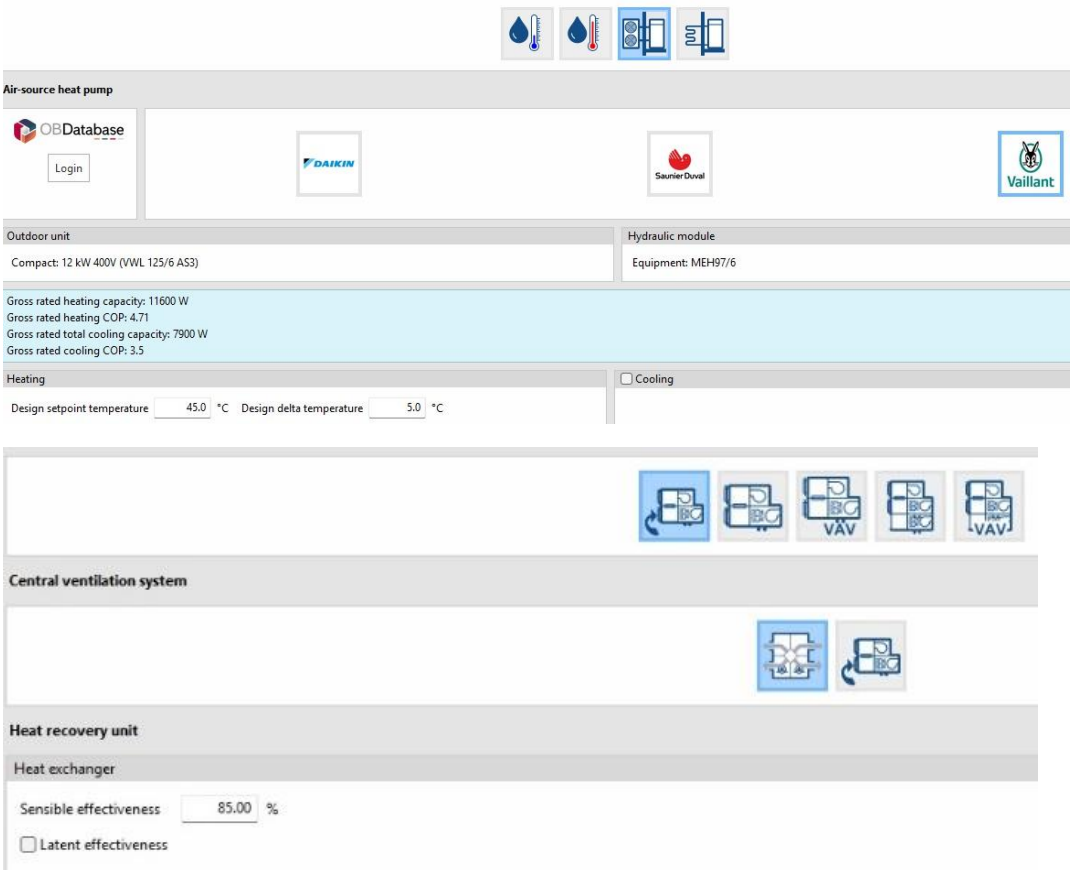
- Case 1: Improved envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows (U=0.8 W/m^{2}K), air-water heat pump, mechanical ventilation, underfloor heating



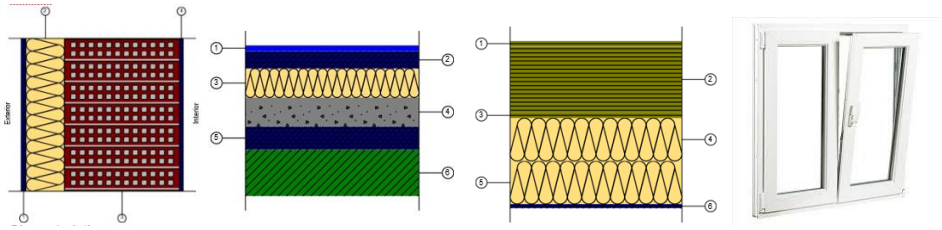


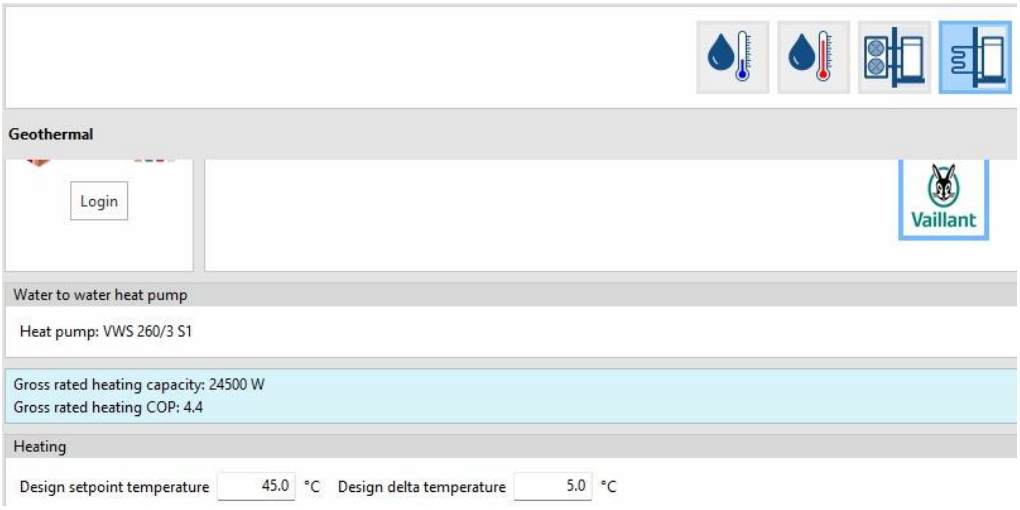
- Case 2: Improved envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), air-water heat pump, mechanical ventilation, underfloor heating

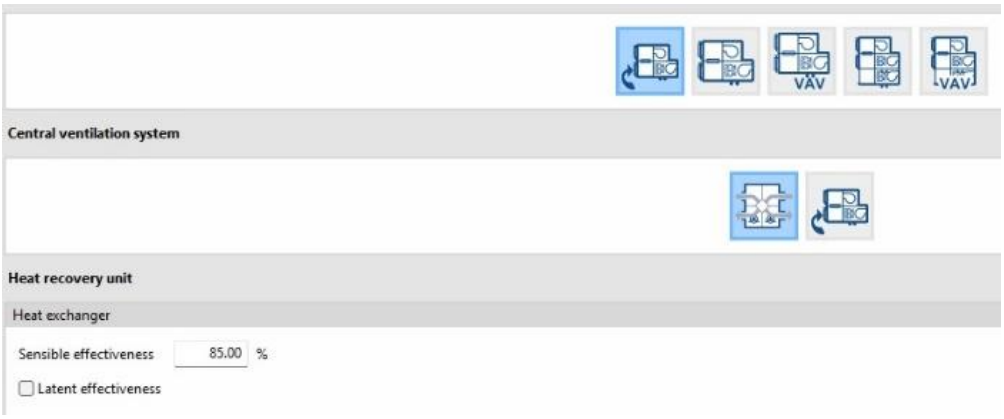




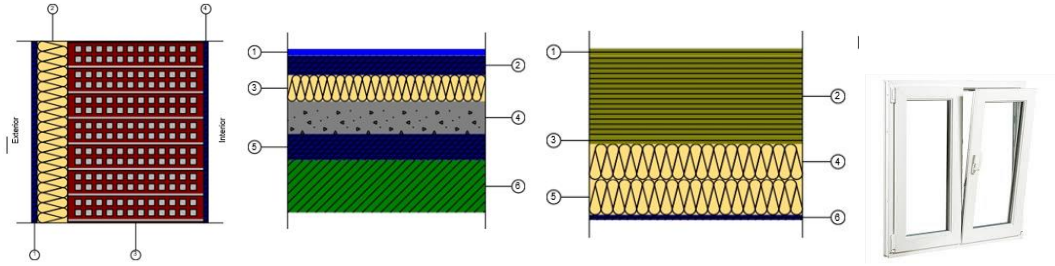
- Case 3: **Improved** envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows), water/ground-water heat pump, mechanical ventilation, underfloor heating

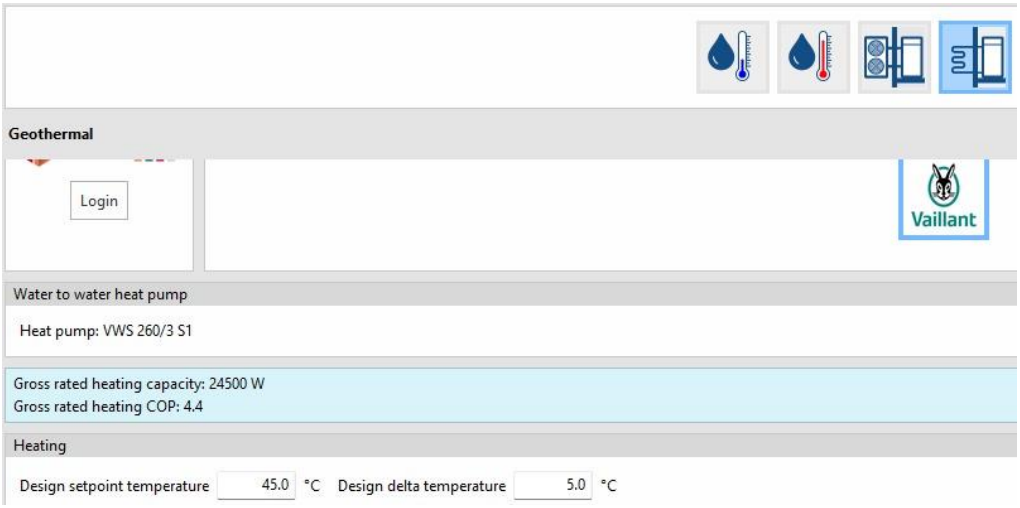


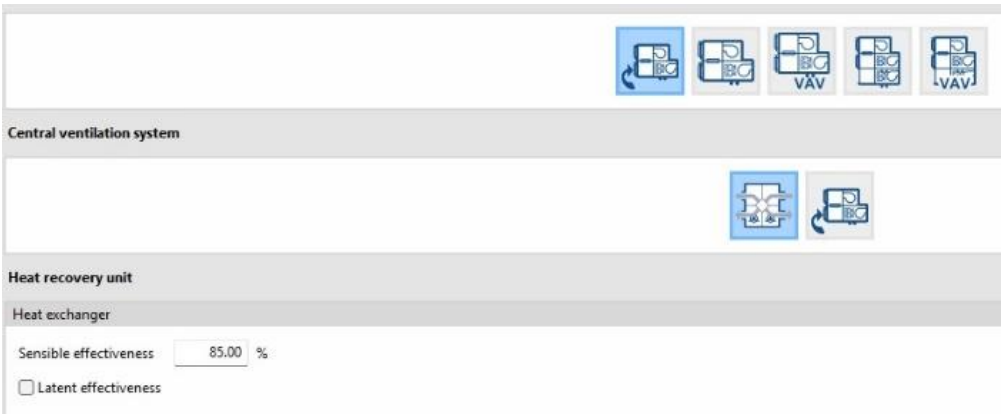




- **Case 4: Improved** envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), water/ground-water heat pump, mechanical ventilation, underfloor heating







3.7. Case results. Energy consumption and Energy Rating of the existing buildings

In this section and in the following one, the annual consumption of final energy, primary energy and non-renewable primary energy corresponding to the different technical services of the building are shown for the initial situation of the building and for the 4 alternatives to improve its energy performance. The consumption of heating and cooling services includes the electricity consumption of the auxiliary equipment of the air conditioning systems.

In addition, the energy rating of the cases studied (initial situation and the 4 improvement alternatives) is also shown. This rating has been calculated following Spanish standards considering its equivalent climate zone: E1

In order to clarify concepts, some definitions are introduced here:

Total primary energy consumption.

Total Primary Energy Consumption in the context of a building energy efficiency analysis refers to the total amount of energy from all sources (like electricity, gas, oil, or renewables) that is required to operate the building, including the energy used to produce and deliver that energy.

More specifically:

• "**Primary energy**" means the energy in its original, raw form—before it is converted into electricity or heat. For example, coal, natural gas, crude oil, or sunlight.

• This includes **energy used on-site** (like gas for heating) and **converted energy** (like electricity), but it also accounts for the **losses that occur during generation, transmission, and distribution**.

So, Total Primary Energy Consumption tells you how much raw energy is ultimately needed to run the building, giving a full picture of its environmental impact.

Primary energy consumption of non-renewable origin.

Primary energy consumption of non-renewable origin refers to the **total amount of non-renewable primary energy** used to operate a building, including:

• **Fossil fuels**: coal, natural gas, and oil

• **Nuclear energy**

• **Any other non-renewable energy sources**

This measurement includes:

• Energy **directly used on-site**, like natural gas for heating

• Energy **used indirectly**, such as electricity generated from coal or gas (including losses from generation and transmission)

Energy consumption at the point of consumption (final energy).

Energy consumption at the point of consumption, also known as **final energy consumption**, refers to the **amount of energy actually used by the building** for its various functions, such as:

• **Heating**

• **Cooling**

• **Lighting**

• **Hot water**

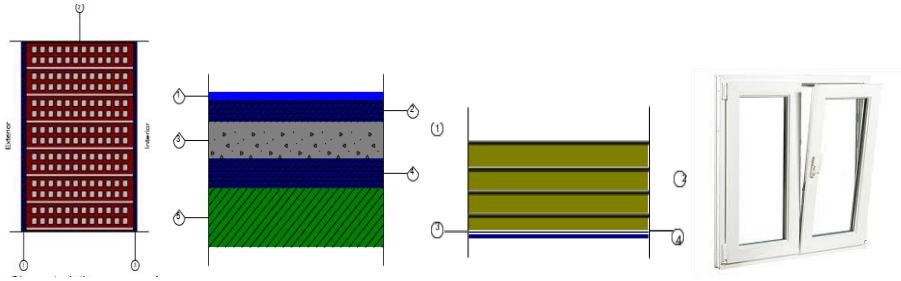
• **Appliances and equipment**

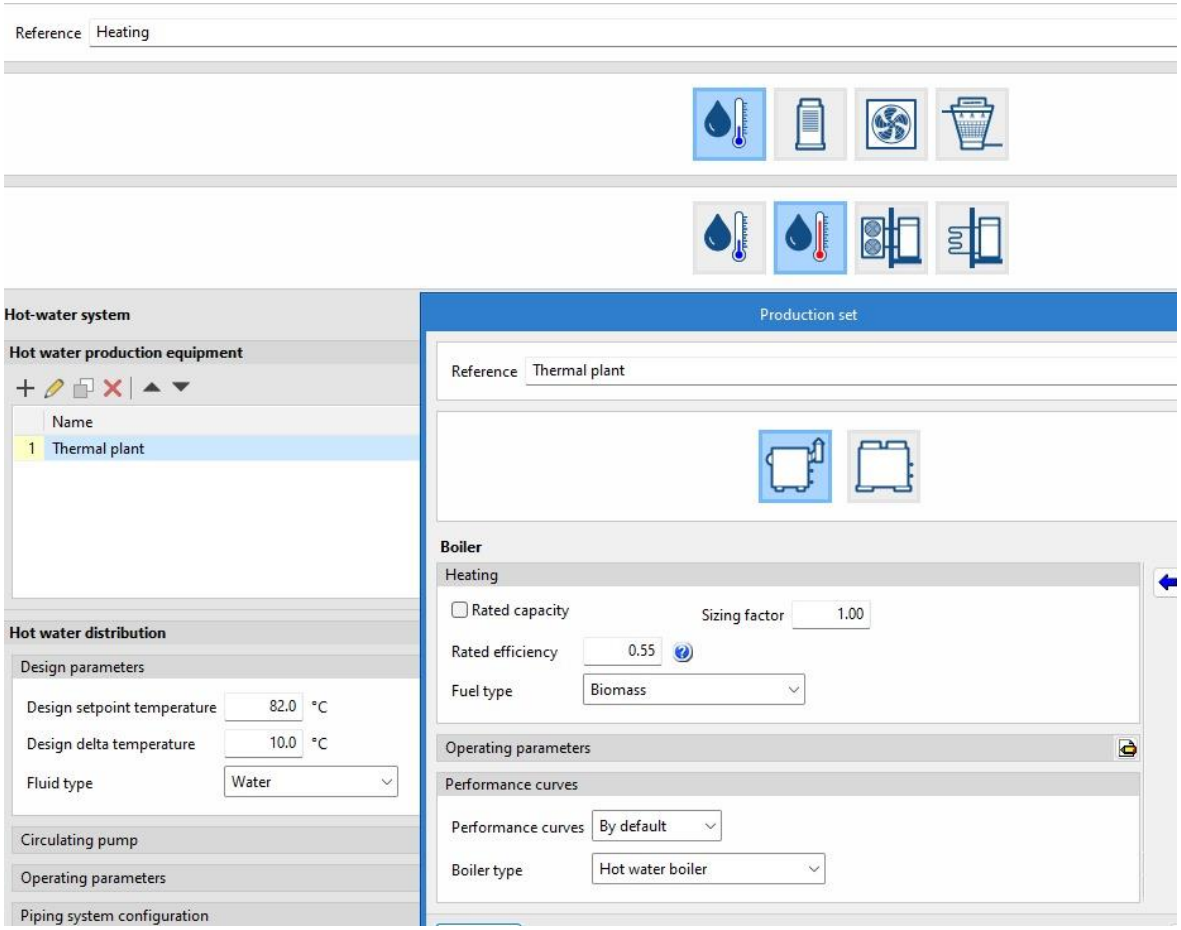
This is the **energy delivered to the building** and **measured at the meter**, such as electricity bills or gas usage. It does **not include energy losses** that occurred during production, conversion, or transmission (which are included in primary energy).

In summary:

- **Final energy** = Energy used **inside the building**, as seen by the user.
- **Primary energy** = Final energy **plus upstream losses** (e.g. power plant efficiency, grid transmission losses).

- Case 0: Existing/initial scenario: envelope without insulation, double glazing windows (U=2.1 W/m^{2}K), solid fuel thermal plant (wood) of low efficiency, radiators





Energy consumption of the technical services of the building

BUILDING (Su= 332.39 m²)

Technical Services	EF		EP_{tot}		EP_{nren}	
	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)
Heating	103602.76	311.69	113279.19	340.81	11951.31	35.96
DHW	20969.03	63.09	49654.65	149.39	40973.36	123.27
Lighting	4286.70	12.90	10150.77	30.54	8376.16	25.20
	128858.49	387.68	173084.94	520.73	61301.16	184.43

where:

Su: Usable living area included in the thermal envelope, m².

EF: Final energy consumed by technical service at point of consumption.

EPtot: Total primary energy consumption.

EPnren: Primary energy consumption of non-renewable origin.

Final energy consumption of the building. Monthly results.

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	kWh/m²-year)
BUILDING (..= 332.39 m²)															
Energy demand	**Heating**	**9963.9**	**8723.8**	**6980.1**	**3377.9**	**1389.0**	**571.1**	**816.3**	**530.6**	**2432.6**	**4407.4**	**7810.9**	**10240.2**	**57243.9**	**172.2**
	DHW	**1700.8**	**1536.2**	**1700.8**	**1645.9**	**1700.8**	**1645.9**	**1700.8**	**1700.8**	**1645.9**	**1700.8**	**1645.9**	**1700.8**	**20025.5**	**60.2**
	TOTAL	**11664.7**	**10260.0**	**8680.9**	**5023.9**	**3089.8**	**2217.0**	**2517.1**	**2231.4**	**4078.5**	**6108.2**	**9456.8**	**11941.0**	**77269.3**	**232.5**
Biomass	**Heating**	17775.8	15547.7	12259.6	5646.4	2047.6	771.2	1113.3	566.5	3827.8	7549.0	13821.7	18286.0	99212.7	298.5
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	–	–	–	–	–	–	–	–	–	–	–	–	–	
Electricity	**Heating**	443.5	400.6	443.5	395.2	328.7	177.6	248.0	253.6	428.3	398.5	429.2	443.5	4390.1	13.2
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	1780.9	1608.6	1780.9	1723.5	1780.9	1723.5	1780.9	1780.9	1723.5	1780.9	1723.5	1780.9	20969.1	63.1
	Ventilation	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Humidity control	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Lighting	503.0	437.4	481.2	459.3	503.0	459.3	–	–	–	503.0	481.2	459.3	4286.7	12.9
	Cef,total	**20503.3**	**17994.2**	**14965.2**	**8224.3**	**4660.3**	**3131.6**	**3142.2**	**2601.1**	**5979.6**	**10231.5**	**16455.5**	**20969.7**	**128858.6**	**387.7**

where:

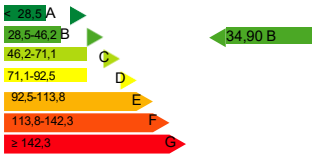
Su: Usable living area included in the thermal envelope, m².

Cef,total: Energy consumption at point of consumption (final energy), kWh/m²-year.

Energy rating of the building: Initial situation/existing building.

Climate zone	E1	**Usage**	Other uses

1. ENERGY RATING OF THE BUILDING IN TERMS OF EMISSIONS

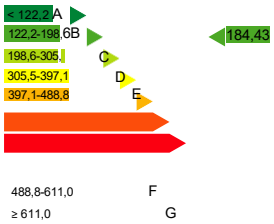
OVERALL INDICATOR	**PARTIAL INDICATORS**			
	**HEATING**		**DHW**	
	Heating emissions [kgCO₂/m²-year].	**A**	DHW emissions [kgCO₂/m²-year].	**E**
	9.74		**20.88**	
	COOLING		**LIGHTING**	
Global emissions [kgCO₂ /m²-year]	Cooling emissions [kgCO₂/m²-year].	**A**	Lighting emissions [kgCO₂/m²-year].	**E**
	0		**4.27**	

The overall rating of the building is expressed in terms of carbon dioxide released into the atmosphere as a result of the building's energy consumption.

	kgCO2/m²-year	**kgCO2-year**
CO2 emissions from electricity consumption	29.52	9812.76
CO2 emissions from other fuels	5.37	1785.83

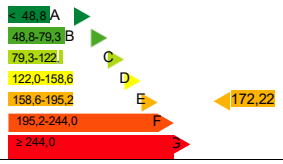
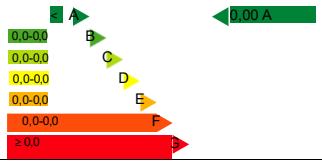
2. ENERGY RATING OF THE BUILDING IN TERMS OF NON-RENEWABLE PRIMARY ENERGY CONSUMPTION

Non-renewable primary energy means energy consumed by the building from non-renewable sources that has not undergone any conversion or transformation process.

OVERALL INDICATOR	**PARTIAL INDICATORS**			
	**HEATING**		**DHW**	
	Primary energy heating [kWh/m²-year]	**A**	Primary energy DHW [kWh/m²-yr]	**E**
	35.96		**123.27**	
	COOLING		**LIGHTING**	
Overall non-renewable primary energy consumption [kWh/m²-year][1]	Primary energy cooling [kWh/m²-year].	**A**	Primary energy lighting [kWh/m²-year].	**E**
	0		**25.2**	

3. PARTIAL RATING OF HEATING AND COOLING ENERGY DEMAND

The heating and cooling energy demand is the energy required to maintain the internal comfort conditions of the building.

HEATING DEMAND	**COOLING DEMAND**
	
Heating demand [kWh/m²-year].	Cooling demand [kWh/m²-year].

1 The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (only tertiary buildings, ventilation, pumping, etc.). Self-consumed electricity is only deducted from the global indicator, not from the partial values.

Erasmus+ Project ID: 2023-1-ES01-KA220-HED-000156652

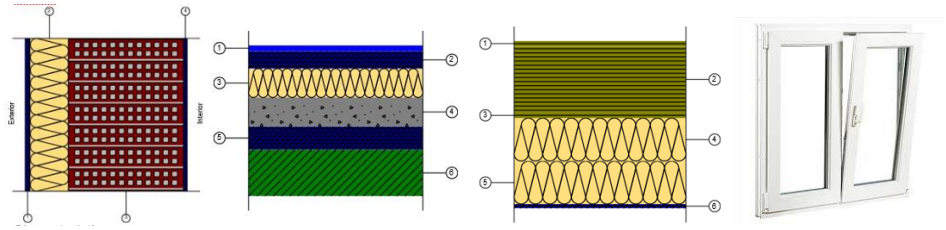
This Erasmus+ Project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the European Commission and Erasmus+ National Agencies cannot be held responsible for any use which may be made of the information contained therein

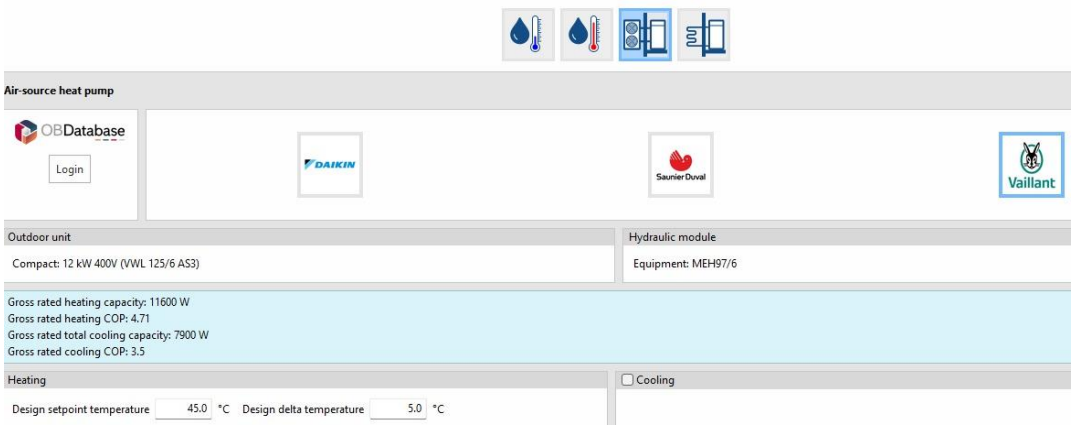
Romanian Case Study

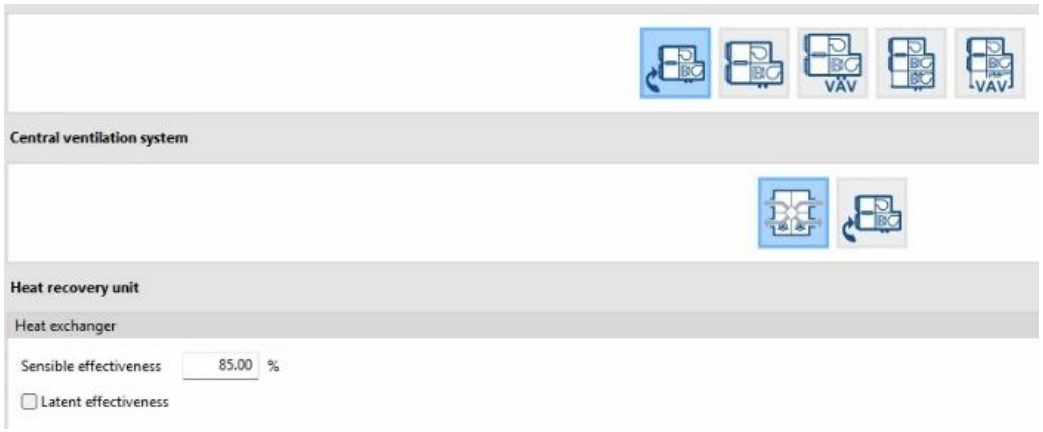
Part II: Analysis of the improvement measures

1. Case Results II. Energy consumption and Energy Rating of the alternatives to improve the building

- Case 1: Improved envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows (U=0.8 W/m^{2}K), air-water heat pump, mechanical ventilation, underfloor heating







Energy consumption of the technical services of the building

BUILDING (Su= 332.39 m²)

Technical Services	EF		EP_{tot}		EP_{nren}	
	(kWh/year) (kWh/m²-year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)
Heating	31695.16	95.36	37463.68	112.71	37368.62	112.43
ACS	20969.03	63.09	49654.65	149.39	40973.36	123.27
Ventilation	567.78	1.71	1344.51	4.04	1109.51	3.34
Lighting	4286.70	12.90	10150.77	30.54	8376.16	25.20
	57518.67	173.05	98613.60	296.68	87827.64	264.23

where:

Su: Usable living area included in the thermal envelope, m².

EF: Final energy consumed by technical service at point of consumption.

EPtot: Total primary energy consumption.

EPnren: Primary energy consumption of non-renewable origin.

Final energy consumption of the building. Monthly results.

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	kWh/m²-year)
BUILDING (A_u = 332.39 m²)															
Energy demand	**Heating**	4609.7	3952.9	2696.4	838.6	54.1	–	8.9	–	672.2	1478.1	3287.2	4919.0	22517.0	67.7
	DHW	1700.8	1536.2	1700.8	1645.9	1700.8	1645.9	1700.8	1700.8	1645.9	1700.8	1645.9	1700.8	20025.5	60.2
	TOTAL	6310.5	5489.1	4397.2	2484.5	1754.9	1645.9	1709.7	1700.8	2318.1	3178.9	4933.1	6619.8	42542.5	128.0
Diesel C (Substitution system)	**Heating**	6459.3	5544.9	3824.0	1198.0	77.2	–	10.2	–	957.4	2100.1	4629.9	6894.2	31695.1	95.4
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	–	–	–	–	–	–	–	–	–	–	–	–	–	
Electricity	**Heating**	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	1780.9	1608.6	1780.9	1723.5	1780.9	1723.5	1780.9	1780.9	1723.5	1780.9	1723.5	1780.9	20969.1	63.1
	Ventilation	66.6	57.9	63.7	60.8	66.6	60.8	–	–	–	66.6	63.7	60.8	567.8	1.7
	Humidity control	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Lighting	503.0	437.4	481.2	459.3	503.0	459.3	–	–	–	503.0	481.2	459.3	4286.7	12.9
	$C_{ef,total}$	8809.9	7648.8	6149.8	3441.6	2427.8	2243.6	1791.1	1780.9	2680.9	4450.7	6898.3	9195.3	57518.7	173.0

where:

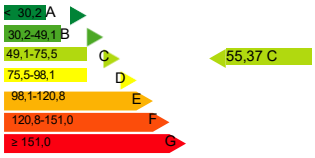
Su: Usable living area included in the thermal envelope, m².

$C_{ef,total}$: Energy consumption at point of consumption (final energy), kWh/m²-year.

Energy rating of the building: Case 1 Improvement.

Climate zone	E1	**Use**	Other uses

1. ENERGY RATING OF THE BUILDING IN TERMS OF EMISSIONS

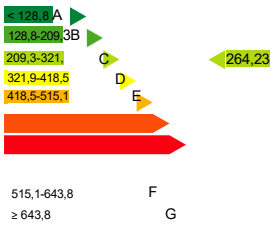
OVERALL INDICATOR	**PARTIAL INDICATORS**			
	HEATING		**DHW**	
	Heating emissions [kgCO₂/m²-year].	**B**	DHW emissions [kgCO₂/m²-year].	**E**
	29.66		**20.88**	
	COOLING		**LIGHTING**	
Global emissions [kgCO /m²-year][1]	Cooling emissions [kgCO₂/m²-year].	**A**	Lighting emissions [kgCO₂/m²-year].	**E**
	0		**4.27**	

The overall rating of the building is expressed in terms of carbon dioxide released into the atmosphere as a result of the building's energy consumption.

	kgCO2/m²-year	**kgCO2-year**
CO2 emissions from electricity consumption	25.72	8547.58
CO2 emissions from other fuels	29.66	9857.19

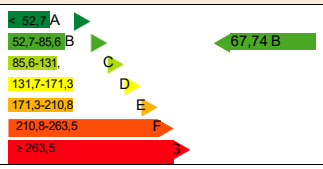
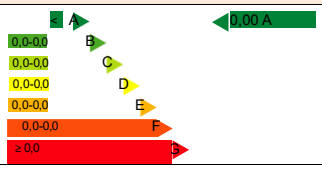
2. ENERGY RATING OF THE BUILDING IN TERMS OF NON-RENEWABLE PRIMARY ENERGY CONSUMPTION

Non-renewable primary energy means energy consumed by the building from non-renewable sources that has not undergone any conversion or transformation process.

OVERALL INDICATOR	**PARTIAL INDICATORS**			
	HEATING		**DHW**	
	Primary energy heating [kWh/m²-year]	**B**	Primary energy DHW [kWh/m²-yr]	**E**
	112.43		**123.27**	
	COOLING		**LIGHTING**	
Overall non-renewable primary energy consumption [kWh/m²-year][1]	Primary energy cooling [kWh/m²-year]	**A**	Primary energy lighting [kWh/m²-year].	**E**
	0		**25.2**	

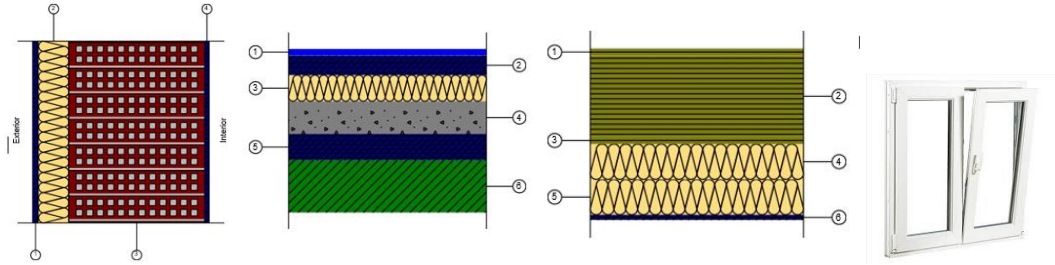
3. PARTIAL RATING OF HEATING AND COOLING ENERGY DEMAND

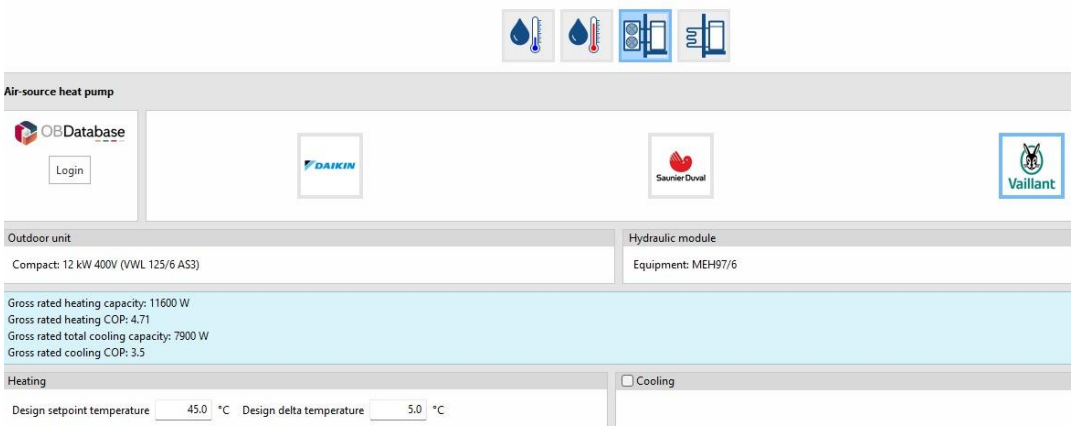
The heating and cooling energy demand is the energy required to maintain the internal comfort conditions of the building.

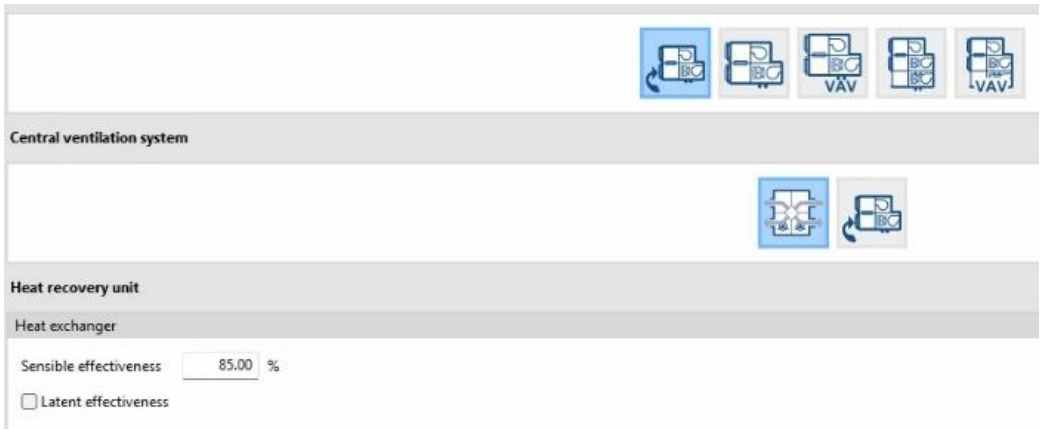
HEATING DEMAND	**COOLING DEMAND**
	
Heating demand [kWh/m²-year].	Cooling demand [kWh/m²-year].

1 The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (only tertiary buildings, ventilation, pumping, etc.). Self-consumed electricity is only deducted from the global indicator, not from the partial values.

- Case 2: Improved envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), air-water heat pump, mechanical ventilation, underfloor heating







Energy consumption of the technical services of the building

BUILDING (Su= 332.39 m²)

Technical Services	EF		EP_{tot}		EP_{nren}	
	(kWh/year) (kWh/m²-year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)
Heating	31041.55	93.39	36691.22	110.39	36598.15	110.11
ACS	20969.03	63.09	49654.65	149.39	40973.36	123.27
Ventilation	567.78	1.71	1344.51	4.04	1109.51	3.34
Lighting	4286.70	12.90	10150.77	30.54	8376.16	25.20
	56865.06	171.08	97841.14	294.36	87057.17	261.92

where:

Su: Usable living area included in the thermal envelope, m².

EF: Final energy consumed by technical service at point of consumption.

EPtot: Total primary energy consumption.

EPnren: Primary energy consumption of non-renewable origin.

Final energy consumption of the building. Monthly results.

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	kWh/m²-year)
BUILDING (S_u= 332.39 m²)															
Energy demand	Heating	4424.2	3828.3	2868.1	871.9	85.8	0.6	22.8	--	743.7	1485.6	3232.8	4741.6	22055.2	66.4
	DHW	1700.8	1638.2	1700.8	1646.9	1700.8	1646.9	1700.8	1700.8	1646.9	1700.8	1646.9	1700.8	20025.6	60.2
	TOTAL	6125.0	5364.5	4368.9	2517.8	1786.4	1646.4	1723.6	1700.8	2389.6	3186.3	4878.8	6442.4	42080.8	126.6
Diesel C (Substitution system)	Heating	6195.1	5369.0	3771.8	1245.6	93.2	--	29.5	--	1060.9	2082.9	4553.0	6640.6	31041.5	93.4
	Cooling	--	--	--	--	--	--	--	--	--	--	--	--	--	
	DHW	--	--	--	--	--	--	--	--	--	--	--	--	--	
Electricity	Heating	--	--	--	--	--	--	--	--	--	--	--	--	--	
	Cooling	--	--	--	--	--	--	--	--	--	--	--	--	--	
	DHW	1780.9	1608.6	1780.9	1723.5	1780.9	1723.5	1780.9	1780.9	1723.5	1780.9	1723.5	1780.9	20969.1	63.1
	Ventilation	66.6	57.9	63.7	60.8	66.6	60.8	--	--	--	66.6	63.7	60.8	567.8	1.7
	Humidity control	--	--	--	--	--	--	--	--	--	--	--	--	--	
	Lighting	503.0	437.4	481.2	459.3	503.0	459.3	--	--	--	503.0	481.2	459.3	4286.7	12.9
	$C_{ef,total}$	3645.7	7473.0	6097.6	3489.2	2443.8	2243.6	1310.4	1780.8	2784.4	4433.6	6821.4	8841.6	56886.1	171.1

where:

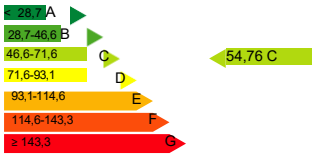
Su: Usable living area included in the thermal envelope, m².

Cef,total: Energy consumption at point of consumption (final energy), kWh/m²-year.

Energy rating of the building: Case 2 Improvement.

Climate zone	E1	**Use**	Other uses

1. ENERGY RATING OF THE BUILDING IN TERMS OF EMISSIONS

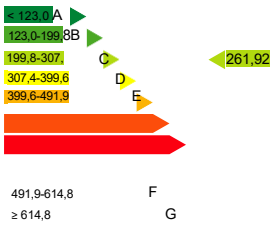
OVERALL INDICATOR	**PARTIAL INDICATORS**			
	HEATING		**DHW**	
	Heating emissions [kgCO₂/m²-year].	**B**	DHW emissions [kgCO₂/m²-year].	**E**
	29.04		**20.88**	
	COOLING		**LIGHTING**	
Global emissions [kgCO /m²-year][1]	Cooling emissions [kgCO₂/m²-year].	**A**	Lighting emissions [kgCO₂/m²-year].	**E**
	0		**4.27**	

The overall rating of the building is expressed in terms of carbon dioxide released into the atmosphere as a result of the building's energy consumption.

	kgCO2/m²-year	**kgCO2-year**
CO2 emissions from electricity consumption	25.72	8547.58
CO2 emissions from other fuels	29.04	9653.92

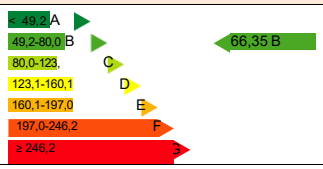
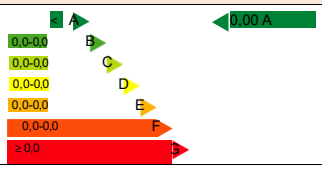
2. ENERGY RATING OF THE BUILDING IN TERMS OF NON-RENEWABLE PRIMARY ENERGY CONSUMPTION

Non-renewable primary energy means energy consumed by the building from non-renewable sources that has not undergone any conversion or transformation process.

OVERALL INDICATOR	**PARTIAL INDICATORS**			
	HEATING		**DHW**	
	Primary energy heating [kWh/m²-year]	**B**	Primary energy DHW [kWh/m²-yr]	**E**
	110.11		**123.27**	
	COOLING		**LIGHTING**	
Overall non-renewable primary energy consumption [kWh/m²-year][1]	Primary energy cooling [kWh/m²-year] [kWh/m²-year].	**A**	Primary energy lighting [kWh/m²-year].	**E**
	0		**25.2**	

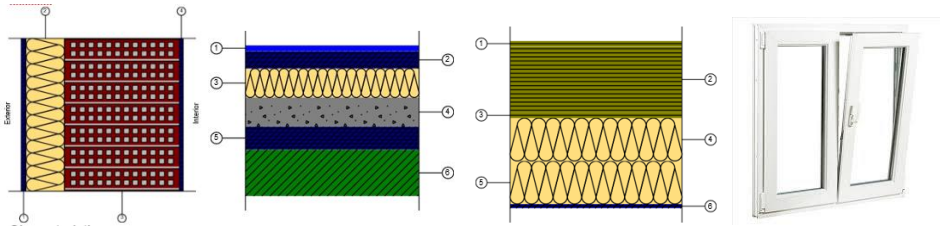
3. PARTIAL RATING OF HEATING AND COOLING ENERGY DEMAND

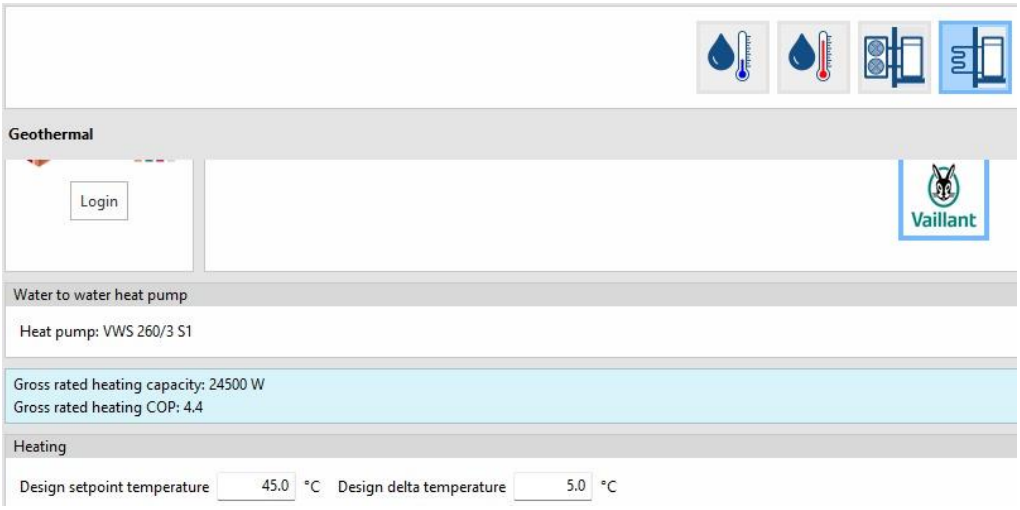
The heating and cooling energy demand is the energy required to maintain the internal comfort conditions of the building.

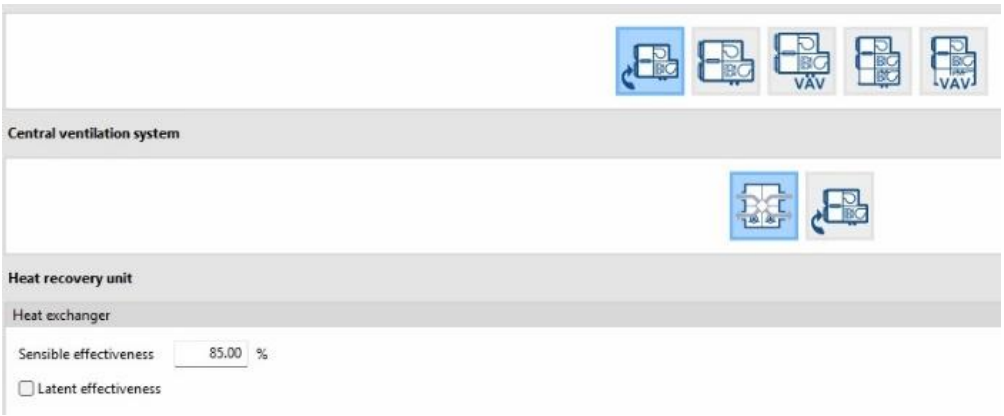
HEATING DEMAND	**COOLING DEMAND**
	
Heating demand [kWh/m²-year].	Cooling demand [kWh/m²-year].

1 The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (only tertiary buildings, ventilation, pumping, etc.). Self-consumed electricity is only deducted from the global indicator, not from the partial values.

- Case 3: Improved envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows), water/ground-water heat pump, mechanical ventilation, underfloor heating







Energy consumption of the technical services of the building

BUILDING (Su= 332.39 m²)

Technical services	EF		EP_{tot}		EP_{nren}	
	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)
Heating	27893.02	83.92	32969.48	99.19	32885.72	98.94
DHW	20969.03	63.09	49654.65	149.39	40973.36	123.27
Ventilation	567.78	1.71	1344.51	4.04	1109.51	3.34
Lighting	4286.70	12.90	10150.77	30.54	8376.16	25.20
	53716.53	161.61	94119.73	283.16	83345.07	250.75

where:

Su: Usable living area included in the thermal envelope, m².

EF: Final energy consumed by technical service at point of consumption.

EPtot: Total primary energy consumption.

EPnren: Primary energy consumption of non-renewable origin.

Final energy consumption of the building. Monthly results.

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	kWh/m²-year)
BUILDING (Su = 332.39 m²)															
Energy demand	**Heating**	**4049.6**	**3494.1**	**2366.2**	**697.8**	**37.6**	–	**2.2**	–	**594.1**	**1272.1**	**2921.5**	**4362.1**	**19797.4**	**59.6**
	DHW	**1700.8**	**1536.2**	**1700.8**	**1645.9**	**1700.8**	**1645.9**	**1700.8**	**1700.8**	**1645.9**	**1700.8**	**1645.9**	**1700.8**	**20025.5**	**60.2**
	TOTAL	**5750.4**	**5030.3**	**4067.0**	**2343.8**	**1738.4**	**1645.9**	**1703.0**	**1700.8**	**2240.1**	**2972.9**	**4567.4**	**6062.9**	**39822.8**	**119.8**
Diesel C (Substitution system)	**Heating**	5679.6	4905.5	3363.0	996.9	53.7	–	1.1	–	845.8	1810.3	4124.0	6113.1	27893.0	83.9
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	–	–	–	–	–	–	–	–	–	–	–	–	–	
Electricity	**Heating**	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	1780.9	1608.6	1780.9	1723.5	1780.9	1723.5	1780.9	1780.9	1723.5	1780.9	1723.5	1780.9	20969.1	63.1
	Ventilation	66.6	57.9	63.7	60.8	66.6	60.8	–	–	–	66.6	63.7	60.8	567.8	1.7
	Humidity control	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Lighting	503.0	437.4	481.2	459.3	503.0	459.3	–	–	–	503.0	481.2	459.3	4286.7	12.9
	$Cef_{,tot}$	**8030.2**	**7009.5**	**5688.9**	**3240.5**	**2404.3**	**2243.6**	**1782.0**	**1780.9**	**2569.3**	**4160.9**	**6392.3**	**8414.2**	**53716.6**	**161.6**

where:

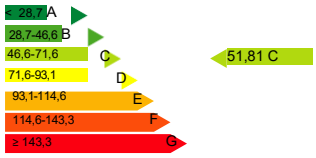
Su: Usable living area included in the thermal envelope, m².

Cef,total: Energy consumption at point of consumption (final energy), kWh/m²-year.

Energy rating of the building: Case 3 Improvement.

Climate zone	E1	Use	Other uses

1. ENERGY RATING OF THE BUILDING IN TERMS OF EMISSIONS

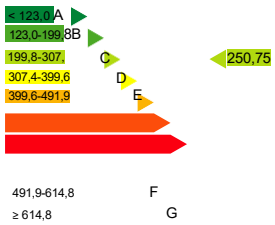
OVERALL INDICATOR	PARTIAL INDICATORS			
	HEATING		DHW	
	Heating emissions [kgCO₂/m²-year].	B	DHW emissions [kgCO₂/m²-year].	E
	26.1		20.88	
	COOLING		LIGHTING	
Global emissions [kgCO₂ /m²-year]	Cooling emissions [kgCO₂/m²-year].	A	Lighting emissions [kgCO₂/m²-year].	E
	0		4.27	

The overall rating of the building is expressed in terms of carbon dioxide released into the atmosphere as a result of the building's energy consumption.

	kgCO2/m²-year	kgCO2-year
CO2 emissions from electricity consumption	25.72	8547.58
CO2 emissions from other fuels	26.10	8674.73

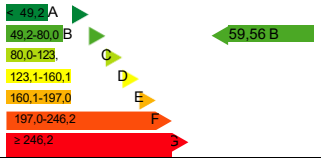
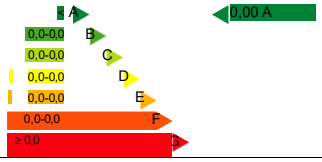
2. ENERGY RATING OF THE BUILDING IN TERMS OF NON-RENEWABLE PRIMARY ENERGY CONSUMPTION

Non-renewable primary energy means energy consumed by the building from non-renewable sources that has not undergone any conversion or transformation process.

OVERALL INDICATOR	PARTIAL INDICATORS			
	HEATING		DHW	
	Primary energy heating [kWh/m²-year]	B	Primary energy DHW [kWh/m²-yr]	E
	98.94		123.27	
	COOLING		LIGHTING	
Overall non-renewable primary energy consumption [kWh/m²-year][1]	Primary energy cooling [kWh/m²-year].	A	Primary energy lighting [kWh/m²-year].	E
	0		25.2	

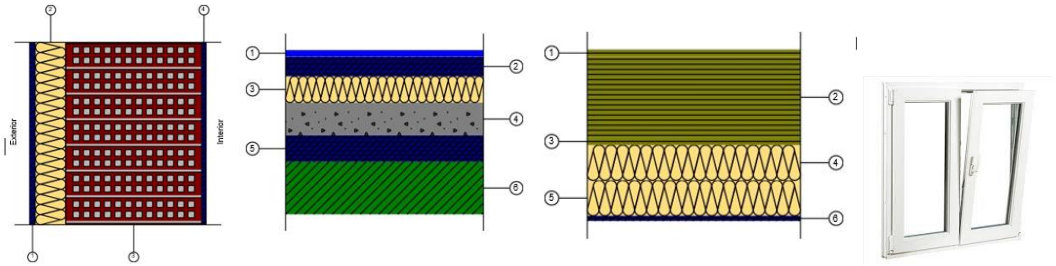
3. PARTIAL HEATING AND COOLING ENERGY DEMAND RATING

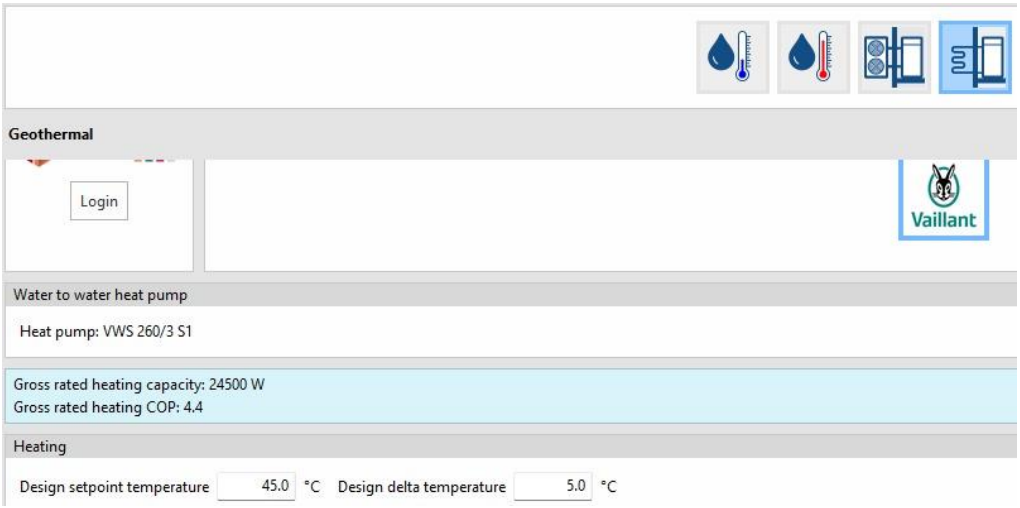
The energy demand for heating and cooling is the energy required to maintain the internal comfort conditions of the building.

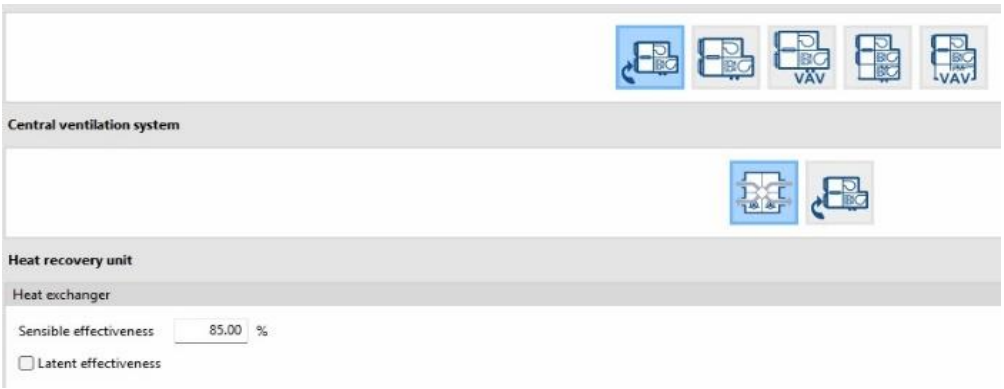
HEATING DEMAND	COOLING DEMAND
	
Heating demand [kWh/m²-year].	Cooling demand [kWh/m²-year].

1 The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (only tertiary buildings, ventilation, pumping, etc.). Self-consumed electricity is only deducted from the global indicator, not from the partial values.

- **Case 4: Improved envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), water/ground-water heat pump, mechanical ventilation, underfloor heating**







Energy consumption of the technical services of the building

BUILDING (Su= 332.39 m²)

Technical services	EF		EP_{tot}		EP_{nren}	
	(kWh/year) (kWh/m²-year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)	(kWh/year)	(kWh/m²-year)
Heating	31041.55	93.39	36691.22	110.39	36598.15	110.11
ACS	20969.03	63.09	49654.65	149.39	40973.36	123.27
Ventilation	567.78	1.71	1344.51	4.04	1109.51	3.34
Lighting	4286.70	12.90	10150.77	30.54	8376.16	25.20
	56865.06	171.08	97841.14	294.36	87057.17	261.92

where:

Su: Usable living area included in the thermal envelope, m².

EF: Final energy consumed by technical service at point of consumption.

EPtot: Total primary energy consumption.

EPnren: Primary energy consumption of non-renewable origin.

Final energy consumption of the building. Monthly results.

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	kWh/m²-year)
BUILDING (A_u = 332.39 m²)															
Energy demand	Heating	4424.2	3828.3	2658.1	871.9	65.6	0.5	22.8	--	743.7	1465.5	3232.8	4741.6	22055.2	66.4
	DHW	1700.8	1536.2	1700.8	1645.9	1700.8	1645.9	1700.8	1700.8	1645.9	1700.8	1645.9	1700.8	20025.5	60.2
	TOTAL	6125.0	5364.5	4358.9	2517.8	1766.4	1646.4	1723.6	1700.8	2389.6	3166.3	4878.8	6442.4	42080.6	126.6
Diesel C (Substitution system)	Heating	6195.1	5369.0	3771.8	1245.6	93.2	–	29.5	–	1060.9	2082.9	4553.0	6640.6	31041.5	93.4
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	–	–	–	–	–	–	–	–	–	–	–	–	–	
Electricity	Heating	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–	
	DHW	1780.9	1608.6	1780.9	1723.5	1780.9	1723.5	1780.9	1780.9	1723.5	1780.9	1723.5	1780.9	20969.1	63.1
	Ventilation	66.6	57.9	63.7	60.8	66.6	60.8	–	–	–	66.6	63.7	60.8	567.8	1.7
	Humidity control	–	–	–	–	–	–	–	–	–	–	–	–	–	
	Lighting	503.0	437.4	481.2	459.3	503.0	459.3	--	--	–	503.0	481.2	459.3	4286.7	12.9
	$Cef_{,total}$	8545.7	7473.0	6097.6	3489.2	2443.8	2243.6	1810.4	1780.9	2784.4	4433.5	6821.4	8941.6	56865.1	171.1

where:

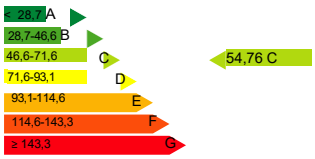
Su: Usable living area included in the thermal envelope, m².

$Cef_{,total}$: Energy consumption at point of consumption (final energy), kWh/m²-year.

Energy rating of the building: Case 4 Improvement.

Climate zone	E1	Use	Other uses

1. ENERGY RATING OF THE BUILDING IN TERMS OF EMISSIONS

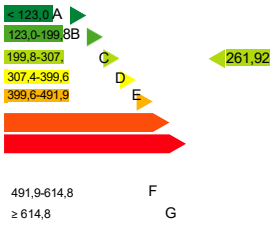
OVERALL INDICATOR	PARTIAL INDICATORS			
	HEATING		DHW	
	Heating emissions [kgCO₂/m²-year].	B	DHW emissions [kgCO₂/m²-year].	E
	29.04		20.88	
	COOLING		LIGHTING	
Global emissions [kgCO /m²-year][1]	Cooling emissions [kgCO₂/m²-year]	A	Lighting emissions [kgCO₂/m²-year]	E
	0		4.27	

The overall rating of the building is expressed in terms of carbon dioxide released into the atmosphere as a result of the building's energy consumption.

	kgCO2/m²-year	kgCO2-year
CO2 emissions from electricity consumption	25.72	8547.58
CO2 emissions from other fuels	29.04	9653.92

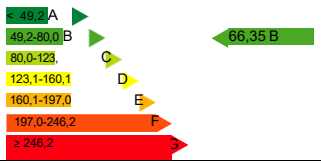
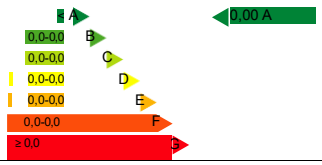
2. ENERGY RATING OF THE BUILDING IN TERMS OF NON-RENEWABLE PRIMARY ENERGY CONSUMPTION

Non-renewable primary energy means energy consumed by the building from non-renewable sources that has not undergone any conversion or transformation process.

OVERALL INDICATOR	PARTIAL INDICATORS			
	HEATING		DHW	
	Primary energy heating [kWh/m²-year]	B	Primary energy ACS [kWh/m²-yr]	E
	110.11		123.27	
	COOLING		LIGHTING	
Overall non-renewable primary energy consumption [kWh/m²-year][1]	Primary energy cooling [kWh/m²-year].	A	Primary energy lighting [kWh/m²-year].	E
	0		25.2	

3. PARTIAL HEATING AND COOLING ENERGY DEMAND RATING

The energy demand for heating and cooling is the energy required to maintain the internal comfort conditions of the building.

HEATING DEMAND	COOLING DEMAND
	
Heating demand [kWh/m²-year].	Cooling demand [kWh/m²-year].

1 The global indicator is the result of the sum of the partial indicators plus the value of the indicator for auxiliary consumption, if any (only tertiary buildings, ventilation, pumping, etc.). Self-consumed electricity is only deducted from the global indicator, not from the partial values.

2. Analysis of Results. Emissions, Energy Consumption and Energy Rating of the cases

Comparison of results

Final energy consumption (kWh/m2·year)

Technical Services	Case 0 Initial situation	Case 1 Imp 1	Case 2 Imp 2	Case 3 Imp 3	Case 4 Imp 4
Heating	311.69	95.36	93.39	83.92	93.39
DHW	63.09	63.09	63.09	63.09	63.09
Lighting	12.9	12.9	12.9	12.9	12.9
Ventilation	-	1.71	1.71	1.71	1.71
TOTAL	387.68	173.05	171.08	161.61	171.08

Legend

Imp 1- Improvement 1: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 2- Improvement 2: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 3- Improvement 3: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Imp 4- Improvement 4: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Total primary energy consumption (kWh/m2·year)

Technical Services	Case 0 Initial situation	Case 1 Imp 1	Case 2 Imp 2	Case 3 Imp 3	Case 4 Imp 4
Heating	340.81	112.71	110.39	99.19	110.39
DHW	149.39	149.39	149.39	149.39	149.39
Lighting	30.54	30.54	30.54	30.54	30.54
Ventilation	-	4.04	4.04	4.04	4.04
TOTAL	340.81	112.71	110.39	99.19	110.39

Legend

Imp 1- Improvement 1: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 2- Improvement 2: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 3- Improvement 3: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Imp 4- Improvement 4: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Total primary energy consumption from non-renewable origin (kWh/m2·year)

Technical Services	**Case 0** **Initial situation**	**Case 1** **Imp 1**	**Case 2** **Imp 2**	**Case 3** **Imp 3**	**Case 4** **Imp 4**
Heating	35.96	112.43	110.11	98.94	110.11
DHW	123.27	123.27	123.27	123.27	123.27
Lighting	25.2	25.2	25.2	25.2	25.2
Ventilation	-	3.34	3.34	3.34	3.34
TOTAL	184.43	264.24	261.92	250.75	261.92

Legend

Imp 1- Improvement 1: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 2- Improvement 2: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 3- Improvement 3: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Imp 4- Improvement 4: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Building Emissions (kgCO2/m2·year)

Technical Services	Case 0 Initial situation	Case 1 Imp 1	Case 2 Imp 2	Case 3 Imp 3	Case 4 Imp 4
CO2 from electricity	29.52	25.72	25.72	25.72	25.72
CO2 from other fuels	5.37	29.66	29.04	26.1	29.04
TOTAL	34.9	55.37	54.76	51.81	54.76
Energy Rating	B	C	C	C	C

Legend

Imp 1- Improvement 1: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 2- Improvement 2: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ air-water heat pump

Imp 3- Improvement 3: Improved thermal envelope (exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and the slab floors with 10 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Imp 4- Improvement 4: Improved thermal envelope (exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and the slab floors with 8 cm extruded polystyrene) + triple glazed windows+ water-water heat pump

Erasmus+ Project ID: 2023-1-ES01-KA220-HED-000156652

This Erasmus+ Project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the European Commission and Erasmus+ National Agencies cannot be held responsible for any use which may be made of the information contained therein

Romanian Case Study

Part III: Cost-benefit study of energy efficiency measures

1. Budget of the improvement alternatives

Improvement 1: Improved envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows (U=0.8 W/m²K), air-water heat pump, mechanical ventilation, underfloor heating

- Description of the price

Item	Cost (€ / m²)
10 cm extruded polystyrene insulation	€12.4
30 cm mineral wool insulation	€7.5
15 cm mineral wool wall insulation	€20.4
Triple glazed Windows	€290
Total Estimated Cost (Installed)	**330 €/ m²**

Improvement 1 budget:

Unit	Description	n.	measurement	price €	amount €
m2	10 cm extruded polystyrene insulation for the slab floors	1	407	12.4	5050
m2	30 cm mineral wool for the upper floor	1	460	7.5	3450
m2	15 cm mineral wool for insulating the exterior walls	1	260	20.4	5300
m2	Triple-glazed PVC windows (U= 0.8 W/m²·K)	1	63	290	18400
m2	Aluminium doors	1	12	350	4200
	Heat pump air-water 23 kW	1	1	11000	11000
	Boiler 100l	1	1	300	300

Complete heating system (underfloor system)	1	1	28000	28000
Ventilation system (3 ventilation units)	1	3	3200	9600
			Total	**85300 €**

Improvement 2: Improved envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), air-water heat pump, mechanical ventilation, underfloor heating

- Description of the price

Item	**Cost (€ / m²)**
8 cm extruded polystyrene insulation	€9,92
20 cm mineral wool insulation	€5
10 cm mineral wool wall insulation	€13.5
Triple glazed Windows	€290
Total Estimated Cost (Installed)	**319 €/ m²**

Improvement 1 budget:

Unit	Description	n.	measurement	price €	amount €
m2	8 cm extruded polystyrene insulation for the slab floors	1	407	9,92	4040
m2	20 cm mineral wool for the upper floor	1	460	5	2300
m2	10 cm mineral wool for insulating the exterior walls	1	260	13.5	3550
m2	Triple-glazed PVC windows (U= 0.8 W/m²·K)	1	63	290	18400
m2	Aluminium doors	1	12	350	4200
	Heat pump air-water 23 kW	1	1	11000	11000
	Boiler 100l	1	1	300	300
	Complete heating system (underfloor system)	1	1	28000	28000
	Ventilation system (3 ventilation units)	1	3	3200	9600
				Total	**81390 €**

Improvement 3: Improved envelope (insulating the exterior walls with 15 cm mineral wool, the upper floor with 30 cm mineral wool and insulating the slab floors with 10 cm extruded polystyrene, triple glazed windows (U=0.8 W/m²K), water-water heat pump, mechanical ventilation, underfloor heating

- Description of the price

Item	Cost (€ / m²)
10 cm extruded polystyrene insulation	€12.4
30 cm mineral wool insulation	€7.5
15 cm mineral wool wall insulation	€20.4
Triple glazed Windows	€290
Total Estimated Cost (Installed)	**330 €/ m²**

Improvement 1 budget:

Unit	Description	n.	measurement	price €	amount €
m2	10 cm extruded polystyrene insulation for the slab floors	1	407	12.4 €	5050 €
m2	30 cm mineral wool for the upper floor	1	460	7.5	3450
m2	15 cm mineral wool for insulating the exterior walls	1	260	20.4	5300
m2	Triple-glazed PVC windows (U= 0.8 W/m²·K)	1	63	290	18400
m2	Aluminium doors	1	12	350	4200
	Heat pump water-water 24 kW	1	1	13900	13900
	Boiler 100l	1	1	300	300
	Complete heating system (underfloor system)	1	1	28000	28000
	Ventilation system (3 ventilation units)	1	3	3200	9600
				Total	**88200 €**

Improvement 4: Improved envelope (insulating the exterior walls with 10 cm mineral wool, the upper floor with 20 cm mineral wool and insulating the slab floors with 8 cm extruded polystyrene, triple glazed windows), water-water heat pump, mechanical ventilation, underfloor heating

- Description of the price

Item	Cost (€ / m²)
8 cm extruded polystyrene insulation	€9,92
20 cm mineral wool insulation	€5
10 cm mineral wool wall insulation	€13.5
Triple glazed Windows	€290
Total Estimated Cost (Installed)	**319 €/ m²**

Improvement 1 budget:

Unit	Description	n.	measurement	price €	amount €
m2	8 cm extruded polystyrene insulation for the slab floors	1	407	9,92	4040
m2	20 cm mineral wool for the upper floor	1	460	5	2300
m2	10 cm mineral wool for insulating the exterior walls	1	260	13.5	3550
m2	Triple-glazed PVC windows (U= 0.8 W/m²·K)	1	63	290	18400
m2	Aluminium doors	1	12	350	4200
	Heat pump water-water 24 kW	1	1	13900	13900
	Boiler 100l	1	1	300	300
	Complete heating system (underfloor system)	1	1	28000	28000
	Ventilation system (3 ventilation units)	1	3	3200	9600
				Total	**84290 €**

2. Cost-benefit study of energy efficiency measures

A cost-benefit analysis (CBA) in the context of building energy renovation is a structured evaluation used to determine whether the investment in upgrading a building's energy performance is economically justified.

It compares all expected costs of the renovation against the financial and non-financial benefits it will generate over the building's lifecycle.

In this case study, the CypeTherm Impromevent plus software has been used to perform this analysis.
In this study, two methods have been used to carry out this analysis:

- Simple Payback Period (SPP)
- Net Present Value (NPV)

Method 1: The **Simple Payback Period** is one of the most straightforward methods for evaluating the financial return of an investment in energy efficiency, such as the energy renovation of a building.

The Simple Payback Period (SPP) is the amount of time (typically expressed in years) it takes for the cumulative energy cost savings generated by an investment to equal the initial cost of that investment.

$$\text{SPP} = \frac{\text{Initial Investment Cost}}{\text{Annual Energy Savings}}$$

Method 2: The **Net Present Value** method is one of the most widely used and robust financial tools for evaluating the profitability of an investment over time. In the context of building energy renovation, NPV helps determine whether the long-term energy savings and other benefits outweigh the initial costs of the retrofit.

NPV is the sum of all future cash flows (such as energy savings, maintenance savings, or subsidies), discounted back to their present value, minus the initial investment cost.

It accounts for the time value of money, recognizing that money received (or saved) in the future is worth less than money today.

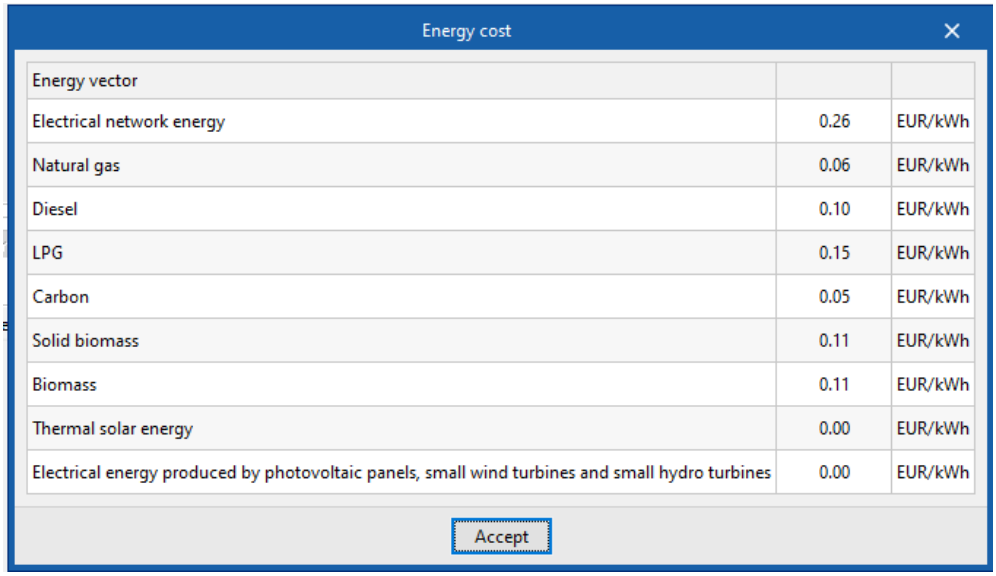
$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t} - I$$

Where:

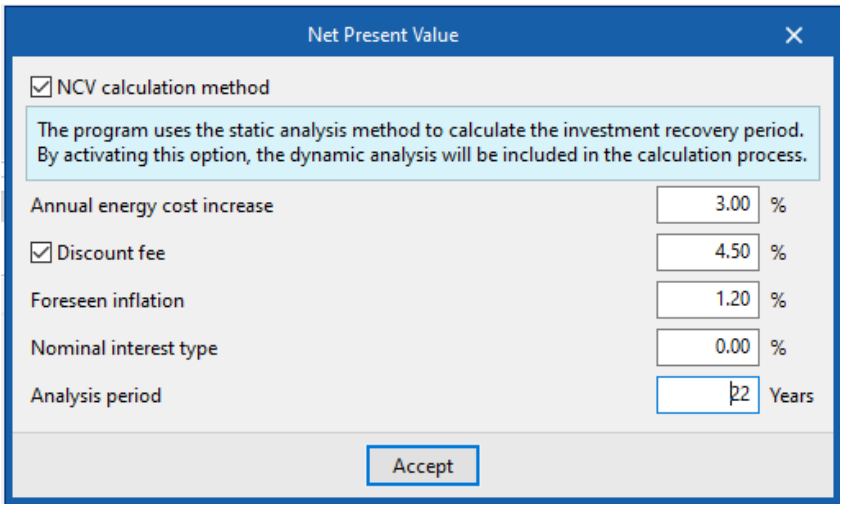
- Bt = Benefits (e.g., energy savings) in year t
- Ct = Operating or maintenance costs in year t
- r = Discount rate (interest rate or cost of capital)
- t = Year (1 to n)
- I = Initial investment cost
- n = Analysis period (in years)

If NPV > 0 → The investment is profitable
If NPV = 0 → The investment breaks even
If NPV < 0 → The investment is not financially viable

Energy cost considered:



Parameters for the Net present value method:



Summary of the results of the Cost-Benefit study of energy efficiency measures:

	Net cost of the investment (EUR)	Annual energy cost (EUR)	Annual net savings (EUR)	Payback (year)	NCV (year)	Annual consumption of non-renewable primary energy (kWh/m²)	Emissions (kg CO2/m²)
Case 0 (initial situation)	0.00	16504.43	0.00	0.00	0.00	187.96	34.70
Case 1	85300.00	9757.83	6746.60	12.64	13.72	264.23	55.38
Case 2	81390.00	9694.97	6809.46	11.95	12.93	261.92	54.76
Case 3	88200.00	9392.78	7111.64	12.40	13.44	250.75	51.82
Case 4	84290.00	9694.97	6809.46	12.38	13.42	261.92	54.76

In the table above, the NCV column answers the following question: How many years will it take to recover the investment, considering the time value of money?

	Net investment cost				Annual net savings				Investment recovery period (year)
	Cost (EUR)	Grants (EUR)	Resultant net cost (EUR)	Difference (EUR)	Energy cost (EUR/year)	Energy savings (EUR/year)	Maintenance (EUR/year)	Net savings (EUR/year)	
Case 0 (Initial situation)	0.00	0.00	0.00	0.00	16504.43	0.00	0.00	0.00	0.00
Case 1	85300.00	0.00	85300.00	85300.00	9757.83	6746.60	0.00	6746.60	12.64
Case 2	81390.00	0.00	81390.00	81390.00	9694.97	6809.46	0.00	6809.46	11.95
Case 3	88200.00	0.00	88200.00	88200.00	9392.78	7111.64	0.00	7111.64	12.40
Case 4	84290.00	0.00	84290.00	84290.00	9694.97	6809.46	0.00	6809.46	12.38

3. Conclusions

The following conclusions can be drawn from this study:

- **Comprehensive Building Assessment Completed**. The case study thoroughly evaluated the current energy performance of an educational building in Romania, using BIM technologies, identifying major inefficiencies in envelope insulation, window performance, heating systems, and ventilation. The building was characterized by high energy consumption and poor thermal comfort, especially during the heating season.
- **Energy Efficiency Measures Identified and Modelled.** A wide range of energy renovation measures were proposed and simulated, including:
  - External wall/roof/floor slab insulation.
  - Replacement of windows with triple glazed.
  - Heating system modernization (by mean of air or water heat pump system and underfloor heating system)
  - Mechanical ventilation with heat recovery
- **Substantial Energy Savings Potential.** The analysis showed that implementing a combination of passive and active measures could reduce the primary energy consumption for heating by 70%. These savings are particularly significant given Romania's cold climate and long heating season.
- **Cost-Benefit Results Vary by Measure.** The financial assessment revealed that:
  - Deep renovation strategies (insolation, window replacement) require higher investment but offer long-term returns.
  - Heating system modernization and the new mechanical ventilation reduce energy consumption.
  - If all the measures considered in the study are implemented, the payback period is considerably reduced (12 years) since greater energy savings are achieved.
- **Combination of Measures Yields Best Results.** The most balanced and sustainable outcome is achieved by combining passive improvements (insulation, airtightness) with active systems (modern heating system and ventilation system). This synergy maximizes energy savings keeping indoor comfort and enhances the building's overall value.
- **Technical and Economic Feasibility Confirmed.** Despite initial investment barriers, the study confirms that energy renovation is technically viable and economically beneficial for the building.

Using metrics such as NPV and SPP, all measures show acceptable economic performance, especially if they are implemented at the same time.

- **Supports National and EU Renovation Goals.** The case aligns with the EU's Green Deal and Renovation Wave strategy, contributing to targets for carbon neutrality, energy efficiency, and healthier indoor environments in public and residential buildings.