Real demonstration results of BEM performance simulation using BIM-SPEED Toolset

Deliverable 4.2 – Energy Performance Report

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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

ENERGY REPORT - BARLAD

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Colophon

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1. General information

1.1 Building description

Barlad Demo Case is a residential building located in Barlad, a city with around 55 000 people of the county of Vaslui in Romania. The building is situated on the street Epureanu, number 40 and has a typical architecture for when it was built (between 1967-1968). **Error! Reference source not found.** shows the aerial view of the building's location.

Figure 1: Aerial view of the urban context and building location

Architecturally, the building has a rectangular shape, with the dimensions of 59 m long and 11.85 m wide. It consists of 5 floors and 40 apartments, and it is divided into 2 areas, part A and part B, with 20 apartments in each part (4 on each floor). The apartments have a different layout. There is one 3-bedroom apartment, two 2-bedroom apartment and one 1-bedroom apartment on each floor.

The building structure consists of brick walls, reinforced concrete slabs and of an uninsulated roof. No major renovation (structural or thermal) has been done and, according to latest structural report, structural renovation work are needed. As for thermal insulation each apartment owner has taken their own measures to improve thermal efficiency of the flats. In this regard, some apartments have a sort of insulation and newer windows, while others have no thermal insulation at all and old wooden windows.

Regarding building services, the heating and the domestic hot water is mostly provided by gas boilers, one per each apartment, and radiators. Only few apartments have a split unit cooling system. Lighting system is mixed, with fluorescent and LED lamps. There is not mechanical ventilation system inside the building. In **Error! Reference source not found.** and Figure 3 show the exterior of the building.

Figure 2: Main façade and back of the building

Figure 3: Side façade of the building

Following a brief summary of the demo general data

Table 1: General information

General information	
Location	Barlad, Romania
Use category	Residential
Building type	Multi-apartment building
Construction year	1966-1967
Renovation year	None
Number of floors	5
Number of apartments/units	40

1.2 GIS and environmental data

Barlad is included in the available weather file list of EnergyPlus[1]. The file presents the temperatures between 2007-2021. In **Error! Reference source not found.**, the average temperatures from Romanian Standard 4839/2014 are shown. In **Error! Reference source not found.**, the external temperature loaded into the BEM model.

Figure 4: Vitoria's Weather file downloaded from Meeren Weather Service

Temp. Average °C												
	Jan.	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Barlad	-2,1	-0,7	3,9	10,3	16,3	19,8	21,8	21,3	16,2	10,4	4,2	-0,9

The following table provides a brief summary of the climate data.

Table 2: General environmental data

General environmental data	
Location	Barlad, Vaslui, Romania
Weather file	ROU_VS_Barlad.151970_TMYx.2007-2021
Altitude [m]	168
Latitude [degrees]	N 44º 25'36.363"
Longitude [degrees]	E 26º6'9.138"
Undistributed temp. of the soil [°C]	10
Network water temperature [°C]	10

The external temperatures imported into the BEM model are showed in the following graph.

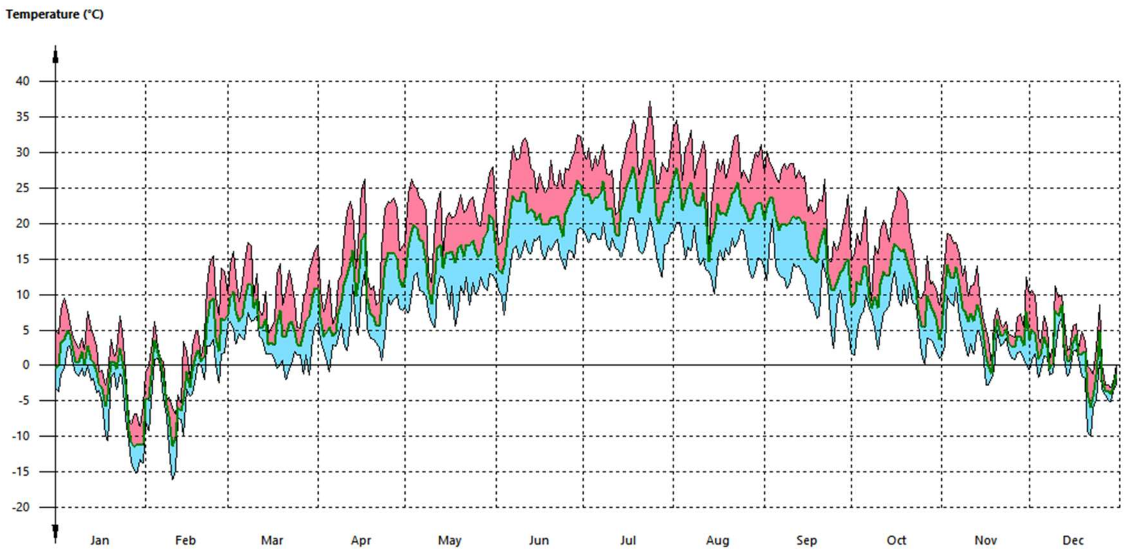


Figure 5: External temperature imported into the BEM model

[1] Source of the epw file for Barlad. https://climate.onebuilding.org/WMO_Region_6_Europe/ROU_Romania/index.html#IDVS_Vaslui-

2. Energy modelling

2.1 BIM-to-BEM procedure and software tools used

To complete the BIM-to-BEM process of Barlad demo case, the CYPETHERM-based procedure has been applied and the following tools have been used:

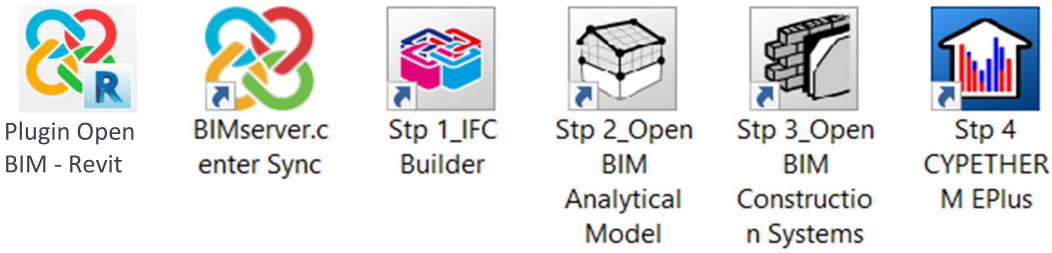


Figure 6: Software tools used to complete the BIM-to-BEM procedure

The BIM model has been developed with Revit software. In the initial stage, the direct export from Revit was used to create an .ifc file. For this step a dedicated add-in "Open BIM-Revit" has been used and the Barlad.ifc file linked to the "BIM SPEED_Central_model" project on the BIMserver.center platform.

Unfortunately, due to some errors on the .ifc file, the export was not entirely usable and a lot of manual work had to be performed. The second solution was to create the .ifc file using IFC Builder, based on 2D drawings exported from the Barlad BIM model. By using IFC builder to create the .ifc file, all the necessary settings, space and object definitions were made directly inside the software, having a concise way of working. This second approach has produced good results and was used further. **Error! Reference source not found.** highlights how one floor is made.

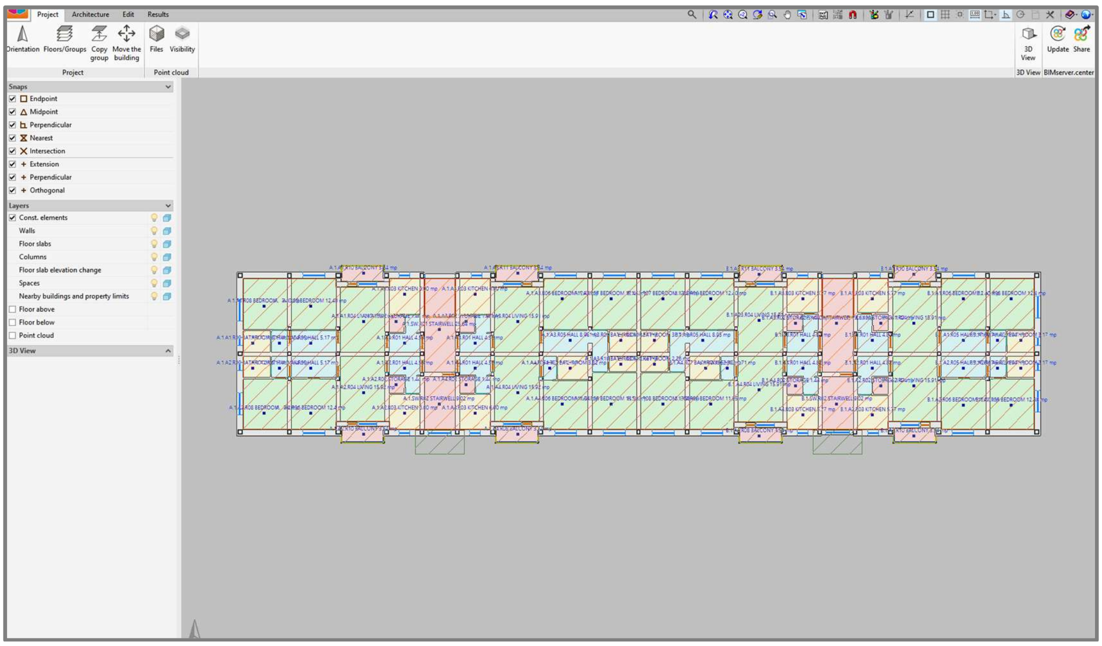


Figure 7: Barlad demo – IFC Builder

The model has then been exported and synchronized in BIMserver.center and open with the Open BIM Analytical model tool to create the analytical model of the building with the definition of all the geometric parameters and the generation of all the spaces needed for the creation of a BEM. A few simplifications and corrections are automatically made and 4 different thermal zones have been defined and associated to the relevant spaces defined previously with IFC Builder:

- Z01 – habitable (where living rooms and bedrooms were included) which is heated
- Z02 – common zones (kitchens and bathrooms were included) which is heated
- Z03 – corridor transition (hallways in the apartments)
- Z04 – non habitable (building staircases, storage spaces, balconies)

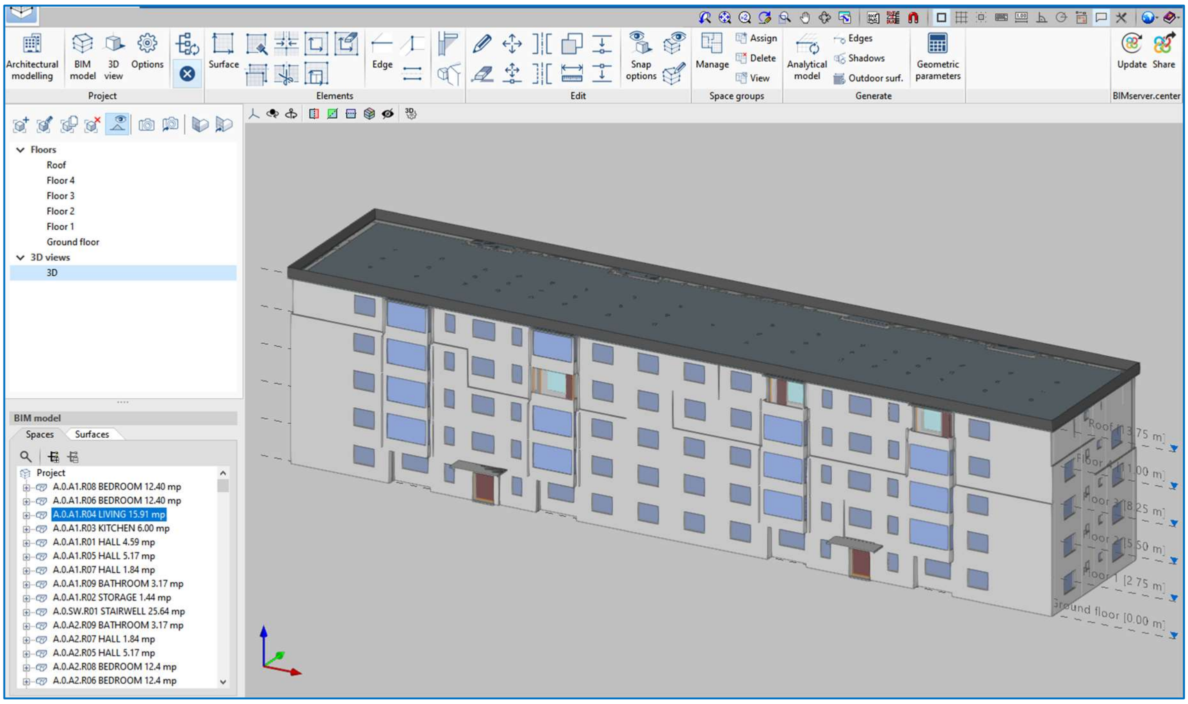


Figure 8: Barlad demo – Open BIM Analytical Model

The analytical model, once generated, has been exported once again in BIMserver.center and the project has been synchronized to be open within the Open BIM Construction Systems for the characterization of the building elements under the thermal point of view. With the Open BIM Construction Systems tool all the building typologies (external walls, party walls, internal partitions, external and internal floors, roofs, etc.) have been defined layer by layer and associated to proper elements.

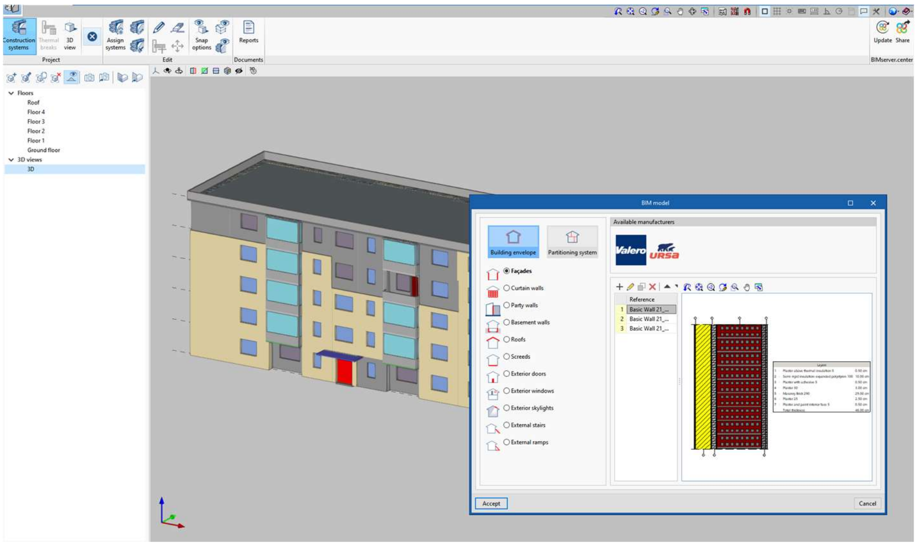


Figure 9: Barlad demo – Open BIM Construction Systems

As in previous steps mentioned, the model has been exported to the BIMserver.center ready to move to last step with the completion of the BEM model with the CYPETHERM EPlus tool for the definition of the systems, the identification of internal gains (equipment, lighting and people) and the usage profiles as described within paragraph 2.3.

2.2 Auditing procedures and data collection

The data was collected on site to develop the BIM model (picture of existing situation) along with any other documentation made available (old floor plans and structural study). No other investigations were made on the building since there was no permission.

2.3 Description of BEM's technical features

Barlad BEM consists of 40 apartments: 10 apartments that have 3 bedrooms, 20 apartments with 2 bedrooms and 10 apartments with 1 bedroom. Figure 10 shows the layout of one floor and Figure 11 presents the 3D of the whole Barlad Demo Case.

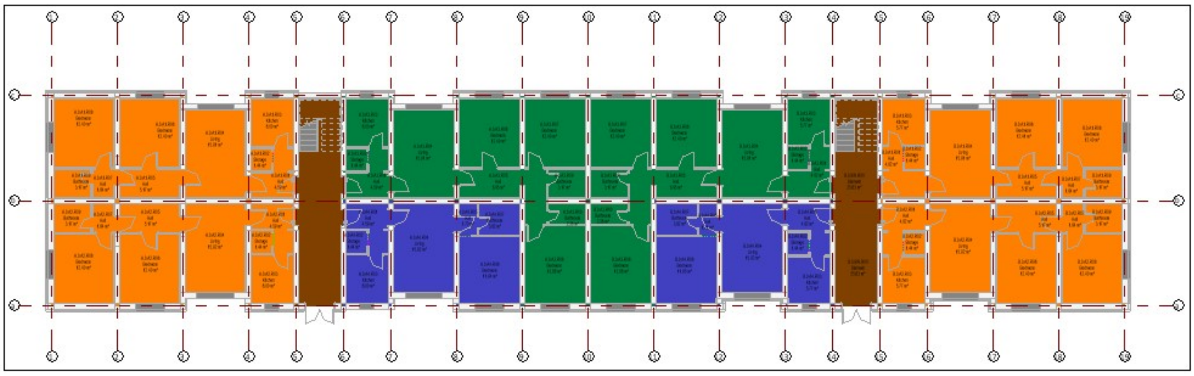


Figure 10: Barlad demo case – distribution of apartments on a floor (blue – 1 bedroom apartment, orange – 2 bedroom apartment, green – 3 bedroom apartment, brown – common spaces)

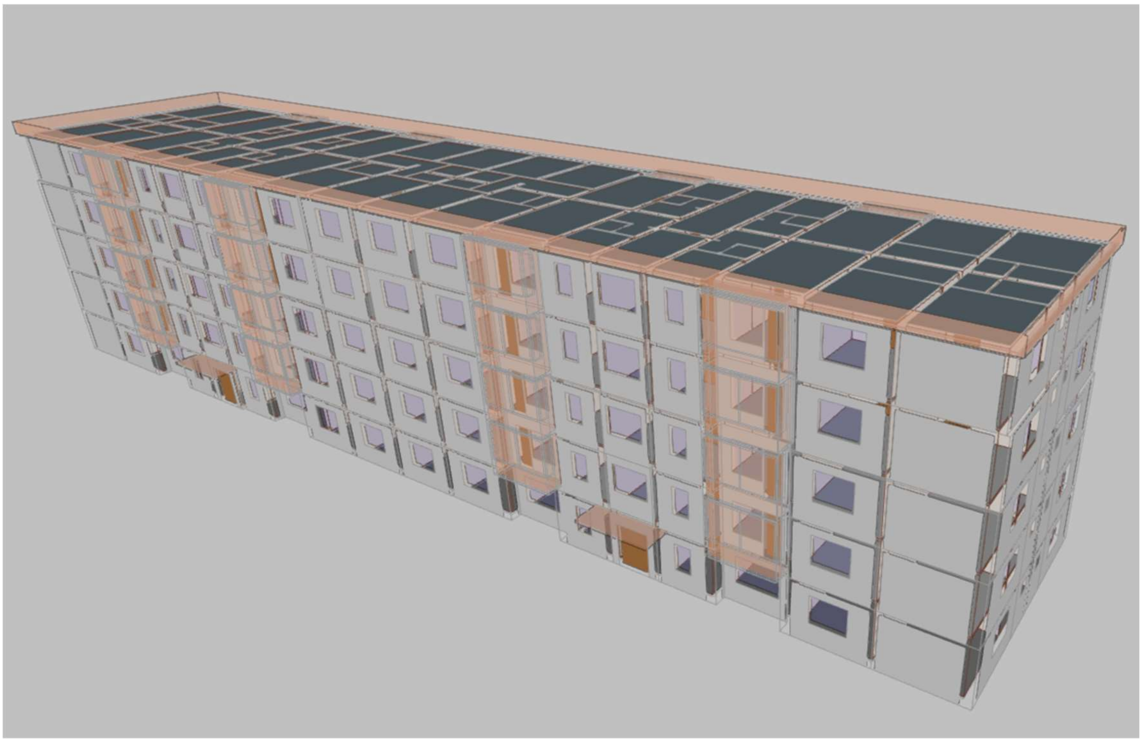
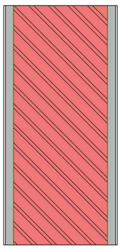
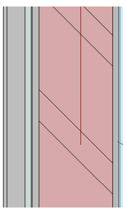


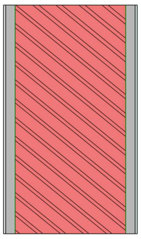
Figure 11: Barlad demo case – BEM 3D graphical representation

2.3.1 Envelope components and materials

This paragraph highlights the elements of the envelope for the Barlad Demo Case. In the tables below the proprieties for each envelope element are shown. Layer 1 represents the first outside layer.

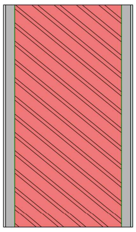
Table 3: Barlad demo case – wall types

	No.	Layer	Density	Thermal conductivity	Specific heat	Thickness	Thermal resistance	R_0
			[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
	1	Plaster and paint exterior	1600	0,70	0,84	0,50	0,007	
	2	Plaster	1700	0,87	0,84	2,50	0,029	
	3	Full brick masonry	1800	0,80	0,87	29,00	0,363	
	4	Plaster	1700	0,87	0,84	2,50	0,029	
	5	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
Wall Type 1	**TOTAL**							0,603
	No.	**Layer**	**Density**	**Thermal conductivity**	**Specific heat**	**Thickness**	**Thermal resistance**	**R_0**
			[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
	1	Plaster and paint exterior	1600	0,70	0,84	0,50	0,007	
	2	Adhesive and plaster	1700	0,87	0,84	1,50	0,017	
	3	Thermal insulation - polystiren	20	0,04	1,46	10,00	2,273	
	4	Plaster	1700	0,87	0,84	2,50	0,029	
	5	Full brick masonry	1800	0,80	0,87	29,00	0,363	
Wall Type 2	6	Plaster	1700	0,87	0,84	2,50	0,029	
	7	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
	8	Plaster and paint exterior	1600	0,70	0,84	0,50	0,007	
	TOTAL							2,893



Internal Wall Type 1

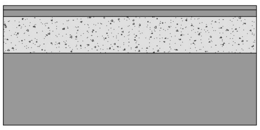
No.	Layer	Density	Thermal conductivity	Specific heat	Thickness	Thermal resistance	R_0
		[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
1	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
2	Plaster	1700	0,87	0,84	2,50	0,029	
3	Full brick masonry	1800	0,80	0,87	25,00	0,313	
4	Plaster	1700	0,87	0,84	2,50	0,029	
5	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
TOTAL							0,634



Internal Wall Type 2

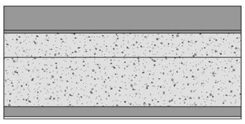
No.	Layer	Density	Thermal conductivity	Specific heat	Thickness	Thermal resistance	R_0
		[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
1	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
2	Plaster	1700	0,87	0,84	1,00	0,011	
3	Full brick masonry	1800	0,80	0,87	7,00	0,088	
4	Plaster	1700	0,87	0,84	1,00	0,011	
5	Plaster and paint interior	1600	0,70	0,84	0,50	0,007	
TOTAL							0,375

Table 4: Barlad demo case – slab types



Ground slab

No.	Layer	Density	Thermal conductivity	Specific heat	Thickness	Thermal resistance	R_0
		[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
1	Finishing layer	2400	2,03	0,92	1,2	0,006	
2	Adhesive and plaster	1700	0,87	0,84	1	0,011	
3	Reinforce Concrete	2400	1,62	0,84	10,00	0,062	
4	Gravel	1800	0,70	0,84	20	0,286	
TOTAL							2,893



Roof slab

No.	Layer	Density	Thermal conductivity	Specific heat	Thickness	Thermal resistance	R_0
		[kg/m^3]	[W/mK]	[kJ/kgK]	[cm]	[m^{2}K/W]	[m^{2}K/W]
1	Gravel	1800	0,70	0,84	5	0,071	
2	Bituminous cardboard	600	0,17	1,46	0,5	0,028	
3	Concrete	2400	1,62	0,84	5	0,031	
4	Reinforce concrete	2400	1,62	0,84	10	0,062	
5	Plaster	1800	0,93	0,84	2	0,022	
6	Finishing layer interior	1600	0,70	0,84	0,50	0,007	
TOTAL							0,351

The following table 5 summarises all the façade openings and windows.

Table 5: Materials

No.	Façade element	Frame Material	Type	Thermal resistance - R
				[m^{2}K/W]
1	Window	wood	Coupled – with 2 glass sheets	0,39
2	Window	PVC	Double – with 2 glass sheets	0,5
3	Door	Metal	One glass sheet	0,17
TOTAL				

2.3.2 HVAC systems

The majority of the apartments is equipped with gas boiler, mounted on the wall, and radiators. The boiler produces heating and domestic hot water. There is just one apartment that is still connected to the centralized heating system of the city of Barlad. The type of gas boiler is unknown so for calculation a non-condensing boiler will be used.

2.3.3 Occupancy, lighting, equipment and operating patterns

Most of the inhabitants of the building consist of aging people and the occupancy is mostly 100% during the winter period. The lighting system is mixed between fluorescent and old lightbulb type with halogen. There is no mechanical ventilation system and only a few apartments have cooling. The cooling system, where installed, is mostly comprised of split units.

3. BEM calibration

The BEM model has not been calibrated with the new BIM SPEED calibration tool since there are no energy bills available or other monitoring data.

4. Building energy performance simulation results

4.1 General considerations

The high energy consumption of the building is mainly caused by to the poor thermal insulation properties or the bad quality of the work performed to mount parts of thermal insulation. Not all the opaque elements are insulated and the windows and doors are old, either wooden frame with no seal measures or old type of PVC windows. The HVAC and lighting system is also old and did not suffer major changes for decades. The equipment are not energy efficient.

4.2 Energy KPIs

The following Energy KPI have been calculated with the CYPETHERM Eplus simulation tool according to D4.1 descriptions.

BS.OPED: Operational Primary Energy Demand

The primary energy demand has been calculated from the final energy consumption at consumption point and multiplied by the conversion factor (specific for Romania) for final energy to primary energy. The table below summarises the primary energy demand related to natural gas and network electricity.

Table 6: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	209,5

Energy vector	$C_{ef,total}$		f_{cep}	$C_{ep,nr}$	
	[kWh/year]	[kWh/m^2 year]	[kWh/year]	[kWh/m^2 year]	[kWh/year]
Natural gas	1524481,2	750,4	1,189	1886007,1	928,3

C_{ef}: *Energy consumption at consumption point (final energy), kWh/m²·year.*
f_{cep}: *Conversion factor for final energy to primary energy.*
C_{ep}: *Primary energy consumption, kWh/m²·year.*

BS.TED: Total Energy Demand

The energy demand of the building is the total amount of energy the technical systems of the building (heating and cooling) have to provide to maintain its indoor environment in comfortable conditions. The table below summarises the results obtained from the calculation of the heating energy demand for the whole building

Table 7: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	162.2
Q_{DHW} [kWh/m²year]	47.3
Q_{TOT} [kWh/m²year]	**209.5**

		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)	Year (kWh/m²·year)
BUILDING (S_u = 2031.64 m²; V = 5383.83 m³)															
Energy demand	**Heating**	**81480.8**	**67760.9**	**37521.8**	**17711.7**	--	--	--	--	--	**16303.9**	**40618.4**	**68119.0**	**329516.5**	**162.2**
	DHW	**8163.5**	**7373.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**96118.7**	**47.3**
	TOTAL	**89644.3**	**75134.4**	**45685.3**	**25611.9**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**24467.4**	**48518.6**	**76282.5**	**425635.2**	**209.5**

BS.TEC: Total Energy Consumption

Total Energy Consumption has been calculated directly using the simulation engine of CYPETHERM EPlus. Following table summarises Primary energy consumption for heating and domestic hot water production.

Table 8: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	762.8
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	111.8
EP_{dhw}[kWh/m²]	77.4
EP_{TOT}[kWh/m²]	**952.1**

		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)	Year (kWh/m²·year)
BUILDING (S_u = 2031.64 m²; V = 5383.83 m³)															
Energy demand	**Heating**	**81480.8**	**67760.9**	**37521.8**	**17711.7**	--	--	--	--	--	**16303.9**	**40618.4**	**68119.0**	**329516.5**	**162.2**
	DHW	**8163.5**	**7373.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**96118.7**	**47.3**
	TOTAL	**89644.3**	**75134.4**	**45685.3**	**25611.9**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**24467.4**	**48518.6**	**76282.5**	**425635.2**	**209.5**
Natural gas (f_{ep} = 1.189)	EF_{heat}	224130.7	197655.6	202561.9	126436.0	--	--	--	--	--	129977.1	192661.8	223498.0	1296921.2	638.4
	EP_{heat}	267836.2	236198.5	242061.5	151091.1	--	--	--	--	--	155322.6	230230.9	267080.1	1549820.8	762.8
	$EP_{nr,heat}$	**266497.0**	**235017.5**	**240851.2**	**150335.6**	--	--	--	--	--	**154546.0**	**229079.8**	**265744.7**	**1542071.7**	**759.0**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	11182.9	10100.7	11182.9	10822.2	11182.9	10822.2	11182.9	11182.9	10822.2	11182.9	10822.2	11182.9	131669.5	64.8
	EP_{dhw}	13363.6	12070.3	13363.6	12932.5	13363.6	12932.5	13363.6	13363.6	12932.5	13363.6	12932.5	13363.6	157345.1	77.4
	$EP_{nr,dhw}$	**13296.7**	**12010.0**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**156558.3**	**77.1**
Electricity (f_{ep} = 1.954)	EF_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,heat}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,dhw}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{light}	8144.1	7356.0	8144.1	7881.4	8144.1	7881.4	8144.1	8144.1	7881.4	8144.1	7881.4	8144.1	95890.5	47.2
	EP_{light}	19285.3	17419.0	19285.3	18663.2	19285.3	18663.2	19285.3	19285.3	18663.2	19285.3	18663.2	19285.3	227068.6	111.8
	$EP_{nr,light}$	**15914.2**	**14374.1**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**187377.0**	**92.2**
Auto-consumed electricity (f_{ep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**243457.7**	**215112.3**	**221888.9**	**145139.6**	**19327.0**	**18703.6**	**19327.0**	**19327.0**	**18703.6**	**149304.1**	**211365.4**	**242825.0**	**1524481.2**	**750.4**
	C_{ep}	**300485.0**	**265687.8**	**274710.3**	**182686.7**	**32648.8**	**31595.6**	**32648.8**	**32648.8**	**31595.6**	**187971.5**	**261826.6**	**299728.9**	**1934234.5**	**952.1**
	$C_{ep,nr}$	**295708.0**	**261401.6**	**270062.1**	**178604.3**	**29211.0**	**28268.7**	**29211.0**	**29211.0**	**28268.7**	**183757.0**	**257348.4**	**294955.6**	**1886007.1**	**928.3**

where:

S_u:	*Residential area of the building, m².*
V:	*Net residential area of the building, m³.*
f_{cep}:	*Conversion factor for final energy to primary energy obtained from non-renewable sources.*
EF:	*Final energy consumed by the system at consumption point, kWh.*
EP:	*Primary energy consumption, kWh.*
EP_{nr}:	*Non-renewable primary energy consumption, kWh.*
$C_{ef,total}$:	*Energy consumption at consumption point (final energy), kWh/m²·year.*
C_{ep}:	*Total primary energy consumption, kWh/m²·year.*
$C_{ep,nr}$:	*Non-renewable primary energy consumption, kWh/m²·year.*

5. Building renovation scenarios

5.1 Renovation scenarios proposed

For the Barlad demo case, the following building renovation scenarios have been assessed according to Task 7.1 premises. The following table summarises the configuration of each scenario.

Table 9: Building renovation scenarios

	Walls insulation	Roof insulation	Windows & Main entrance doors
Scenario 1	☑	☑	☒
Scenario 2	☑	☒	☑
Scenario 3	☑	☑	☑

5.2 Scenario 1: description and results

The first renovation scenario consists of a complete thermal insulation of the building envelope, meaning walls and roof. There is no solution for the ground slab. Main front entrance doors and windows will not be replaced with new ones. The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 10: BS.OPED Operational Primary Energy Demand scenario 1

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	762.8

BS.TED: Total Energy Demand

Table 11: BS.TED Total Energy Demand scenario 1

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m^{2}year]	93.8
Q_{DHW} [kWh/m^{2}year]	47.3
Q_{TOT} [kWh/m^{2}year]	**141.1**

BS.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 12: BS.TEC Total Energy Consumption scenario 1

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m^2]	639.5

		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)	Year (kWh/m²·year)
BUILDING (S_u = 2031.64 m²; V = 5383.83 m³)															
Energy demand	**Heating**	**53908.0**	**43730.4**	**18121.0**	**6133.7**	--	--	--	--	--	**2939.8**	**22049.5**	**43761.8**	**190644.2**	**93.8**
	DHW	**8163.5**	**7373.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**96118.7**	**47.3**
	TOTAL	**62071.5**	**51103.9**	**26284.5**	**14033.9**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**11103.3**	**29949.7**	**51925.3**	**286763.0**	**141.1**
Natural gas (f_{cep} = 1.189)	EF_{heat}	216708.0	190733.9	167558.5	82594.9	--	--	--	--	--	59090.4	162761.4	207732.5	1087179.6	535.1
	EP_{heat}	258966.1	227927.0	200232.4	98700.9	--	--	--	--	--	70613.1	194499.9	248240.4	1299179.7	639.5
	$EP_{nr,heat}$	**257671.3**	**226787.3**	**199231.2**	**98207.4**	--	--	--	--	--	**70260.0**	**193527.4**	**246999.1**	**1292683.8**	**636.3**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	11182.9	10100.7	11182.9	10822.2	11182.9	10822.2	11182.9	11182.9	10822.2	11182.9	10822.2	11182.9	131669.5	64.8
	EP_{dhw}	13363.6	12070.3	13363.6	12932.5	13363.6	12932.5	13363.6	13363.6	12932.5	13363.6	12932.5	13363.6	157345.1	77.4
	$EP_{nr,dhw}$	**13296.7**	**12010.0**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**156558.3**	**77.1**
Electricity (f_{cep} = 1.954)	EF_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,heat}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,dhw}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{light}	8144.1	7356.0	8144.1	7881.4	8144.1	7881.4	8144.1	8144.1	7881.4	8144.1	7881.4	8144.1	95890.5	47.2
	EP_{light}	19285.3	17419.0	19285.3	18663.2	19285.3	18663.2	19285.3	19285.3	18663.2	19285.3	18663.2	19285.3	227068.6	111.8
	$EP_{nr,light}$	**15914.2**	**14374.1**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**187377.0**	**92.2**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**236035.0**	**208190.5**	**186885.5**	**101298.4**	**19327.0**	**18703.6**	**19327.0**	**19327.0**	**18703.6**	**78417.4**	**181465.0**	**227059.5**	**1314739.6**	**647.1**
	C_{ep}	**291614.9**	**257416.3**	**232881.2**	**130296.5**	**32648.8**	**31595.6**	**32648.8**	**32648.8**	**31595.6**	**103261.9**	**226095.5**	**280889.2**	**1683593.4**	**828.7**
	$C_{ep,nr}$	**286882.2**	**253171.4**	**228442.2**	**126476.0**	**29211.0**	**28268.7**	**29211.0**	**29211.0**	**28268.7**	**99471.0**	**221796.0**	**276210.1**	**1636619.1**	**805.6**

where:

- S_u: *Residential area of the building, m².*
- V: *Net volume of the occupied zone in the building, m³.*
- f_{cep}: *Conversion factor for final energy to primary energy obtained from non-renewable sources.*
- EF: *Final energy consumed by the system at consumption point, kWh.*
- EP: *Primary energy consumption, kWh.*
- EP_{nr}: *Non-renewable primary energy consumption, kWh.*
- $C_{ef,total}$: *Energy consumption at consumption point (final energy), kWh/m²·year.*
- C_{ep}: *Total primary energy consumption, kWh/m²·year.*
- $C_{ep,nr}$: *Non-renewable primary energy consumption, kWh/m²·year.*

BS.TES: Total Energy savings

Table 13: BS.TES Total Energy Savings scenario 1

BS.TES: Total Energy Savings			
	Baseline	**Scenario 03**	**SAVING**
EP_{heat}[kWh/m²]	762.8	639.5	123.3

5.3 Scenario 2: description and results

The second renovation scenario consists of a thermal insulation of the building envelope, meaning walls only and no roof insulation. There is no solution for the ground slab. Main front entrance doors and windows will also be replaced with new ones, that have three sheets of glass with PVC frame and a thermal resistance of a minimum of 0,77 [W/m²K]. The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 14: BS.OPED Operational Primary Energy Demand scenario 2

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	762.8

BS.TED: Total Energy Demand

Table 15: BS.TED Total Energy Demand scenario 2

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	112.3
Q_{DHW} [kWh/m²year]	47.3
Q_{TOT} [kWh/m²year]	**159.6**

BS.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 16: BS.TEC Total Energy Consumption scenario 2

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	658.0

BS.TES: Total Energy savings

Table 17: BS.TES Total Energy Savings scenario 2

BS.TES: Total Energy Savings			
	Baseline	Scenario 03	SAVING
EP_{heat}[kWh/m²]	762.8	658.0	104.8

		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)	Year (kWh/m²·year)
BUILDING (S_u = 2031.64 m²; V = 5383.83 m³)															
Energy demand	**Heating**	**63280.6**	**50612.2**	**22023.0**	**7391.3**	--	--	--	--	--	**5339.8**	**27574.9**	**51956.2**	**228177.9**	**112.3**
	DHW	**8163.5**	**7373.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**96118.7**	**47.3**
	TOTAL	**71444.1**	**57985.7**	**30186.5**	**15291.5**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**13503.3**	**35475.1**	**60119.7**	**324296.7**	**159.6**
Natural gas (f_{cep} = 1.189)	EF_{heat}	221313.9	193665.2	172667.2	75735.7	--	--	--	--	--	67992.0	170141.0	217136.8	1118651.9	550.6
	EP_{heat}	264470.2	231429.9	206337.3	90504.1	--	--	--	--	--	81250.4	203318.5	259478.5	1336789.0	658.0
	$EP_{nr,heat}$	**263147.8**	**230272.7**	**205305.6**	**90051.6**	--	--	--	--	--	**80844.2**	**202301.9**	**258181.1**	**1330105.0**	**654.7**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	11182.9	10100.7	11182.9	10822.2	11182.9	10822.2	11182.9	11182.9	10822.2	11182.9	10822.2	11182.9	131669.5	64.8
	EP_{dhw}	13363.6	12070.3	13363.6	12932.5	13363.6	12932.5	13363.6	13363.6	12932.5	13363.6	12932.5	13363.6	157345.1	77.4
	$EP_{nr,dhw}$	**13296.7**	**12010.0**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**156558.3**	**77.1**
Electricity (f_{cep} = 1.954)	EF_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,heat}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,dhw}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{light}	8144.1	7356.0	8144.1	7881.4	8144.1	7881.4	8144.1	8144.1	7881.4	8144.1	7881.4	8144.1	95890.5	47.2
	EP_{light}	19285.3	17419.0	19285.3	18663.2	19285.3	18663.2	19285.3	19285.3	18663.2	19285.3	18663.2	19285.3	227068.6	111.8
	$EP_{nr,light}$	**15914.2**	**14374.1**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**187377.0**	**92.2**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**240641.0**	**211121.8**	**191994.2**	**94439.3**	**19327.0**	**18703.6**	**19327.0**	**19327.0**	**18703.6**	**87319.0**	**188844.6**	**236463.8**	**1346211.8**	**662.6**
	C_{ep}	**297119.0**	**260919.2**	**238986.2**	**122099.8**	**32648.8**	**31595.6**	**32648.8**	**32648.8**	**31595.6**	**113899.3**	**234914.2**	**292127.3**	**1721202.7**	**847.2**
	$C_{ep,nr}$	**292358.8**	**256656.8**	**234516.6**	**118320.3**	**29211.0**	**28268.7**	**29211.0**	**29211.0**	**28268.7**	**110055.1**	**230570.6**	**287392.0**	**1674040.4**	**824.0**

where:

- S_u: *Residential area of the building, m².*
- V: *Net volume of the occupied zone in the building, m³.*
- f_{cep}: *Conversion factor for final energy to primary energy obtained from non-renewable sources.*
- EF: *Final energy consumed by the system at consumption point, kWh.*
- EP: *Primary energy consumption, kWh.*
- EP_{nr}: *Non-renewable primary energy consumption, kWh.*
- $C_{ef,total}$: *Energy consumption at consumption point (final energy), kWh/m²·year.*
- C_{ep}: *Total primary energy consumption, kWh/m²·year.*
- $C_{ep,nr}$: *Non-renewable primary energy consumption, kWh/m²·year.*

5.4 Scenario 3: description and results

The third renovation scenario consists of a complete thermal insulation of the building envelope, meaning walls and roof. There is no solution for the ground slab. Main front entrance doors and windows will also be replaced with new ones, that have three sheets of glass with PVC frame and a thermal resistance of a minimum of 0,77 [W/m²K]. Other renovation work will include replacing vertical piping, the rainwater system and replace the lighting lamps with LED lamps. The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 18: BS.OPED Operational Primary Energy Demand scenario 3

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	762.8

BS.TED: Total Energy Demand

Table 19: BS.TED Total Energy Demand scenario 3

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	77.3
Q_{DHW} [kWh/m²year]	47.3
Q_{TOT} [kWh/m²year]	**124.6**

BS.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 20: BS.TEC Total Energy Consumption scenario 3

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	578.8

BS.TES: Total Energy savings

Table 21: BS.TES Total Energy Savings scenario 3

BS.TES: Total Energy Savings			
	Baseline	Scenario 03	SAVING
EP_{heat}[kWh/m²]	762.8	578.8	184

		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)	Year (kWh/m²·year)
BUILDING (S_u = 2031.64 m²; V = 5383.83 m³)															
Energy demand	**Heating**	**46672.9**	**37417.2**	**13374.0**	**3750.9**	--	--	--	--	--	**1016.4**	**17447.8**	**37434.7**	**157113.7**	**77.3**
	DHW	**8163.5**	**7373.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**8163.5**	**7900.2**	**8163.5**	**96118.7**	**47.3**
	TOTAL	**54836.4**	**44790.6**	**21537.5**	**11651.0**	**8163.5**	**7900.2**	**8163.5**	**8163.5**	**7900.2**	**9179.9**	**25347.9**	**45598.2**	**253232.4**	**124.6**
Natural gas (f_{cep} = 1.189)	EF_{heat}	211103.1	182008.0	154024.6	62236.1	--	--	--	--	--	31143.9	145538.6	197934.2	983988.5	484.3
	EP_{heat}	252268.2	217499.5	184059.4	74372.1	--	--	--	--	--	37216.9	173918.6	236531.4	1175866.2	578.8
	$EP_{nr,heat}$	**251006.9**	**216412.0**	**183139.1**	**74000.3**	--	--	--	--	--	**37030.9**	**173049.0**	**235348.7**	**1169986.9**	**575.9**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	11182.9	10100.7	11182.9	10822.2	11182.9	10822.2	11182.9	11182.9	10822.2	11182.9	10822.2	11182.9	131669.5	64.8
	EP_{dhw}	13363.6	12070.3	13363.6	12932.5	13363.6	12932.5	13363.6	13363.6	12932.5	13363.6	12932.5	13363.6	157345.1	77.4
	$EP_{nr,dhw}$	**13296.7**	**12010.0**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**13296.7**	**12867.8**	**13296.7**	**12867.8**	**13296.7**	**156558.3**	**77.1**
Electricity (f_{cep} = 1.954)	EF_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{heat}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,heat}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{dhw}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,dhw}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{light}	8144.1	7356.0	8144.1	7881.4	8144.1	7881.4	8144.1	8144.1	7881.4	8144.1	7881.4	8144.1	95890.5	47.2
	EP_{light}	19285.3	17419.0	19285.3	18663.2	19285.3	18663.2	19285.3	19285.3	18663.2	19285.3	18663.2	19285.3	227068.6	111.8
	$EP_{nr,light}$	**15914.2**	**14374.1**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**15914.2**	**15400.9**	**15914.2**	**15400.9**	**15914.2**	**187377.0**	**92.2**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**230430.1**	**199464.6**	**173351.6**	**80939.7**	**19327.0**	**18703.6**	**19327.0**	**19327.0**	**18703.6**	**50470.9**	**164242.1**	**217261.2**	**1211548.5**	**596.3**
	C_{ep}	**284917.1**	**246988.8**	**216708.2**	**105967.8**	**32648.8**	**31595.6**	**32648.8**	**32648.8**	**31595.6**	**69865.8**	**205514.2**	**269180.2**	**1560279.9**	**768.0**
	$C_{ep,nr}$	**280217.8**	**242796.1**	**212350.1**	**102268.9**	**29211.0**	**28268.7**	**29211.0**	**29211.0**	**28268.7**	**66241.8**	**201317.6**	**264559.7**	**1513922.3**	**745.2**

where:

S_u: Residential area of the building, m².

V: Net residential area of the building, m³.

f_{cep}: Conversion factor for final energy to primary energy obtained from non-renewable sources.

EF: Final energy consumed by the system at consumption point, kWh.

EP: Primary energy consumption, kWh.

EP_{nr}: Non-renewable primary energy consumption, kWh.

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

C_{ep}: Total primary energy consumption, kWh/m²·year.

$C_{ep,nr}$: Non-renewable primary energy consumption, kWh/m²·year.

6. Time reduction evaluation

Following table shows the results of the time reduction for the Barlad democase. The BIM SPEED process completed as previously described has been compared to the creation of a BEM using a traditional process, based on the expertise of RINA C on similar buildings.

Table 22: Time reduction analysis for the BIM-to-BEM process compared to traditional BEM creation process

	Workflow required for the BEM creation	Traditional process		BIM SPEED PROCESS	
		activity description	time required (working days)	activity description	time required (working days)
1	**BUILDING DATA COLLECTION (site inspection, document/drawing analysis,..), specific data for the thermal characterization are needed**				
	a) direct geometrical measurements (needed if detailed and reliable technical drawings are not available)	Travelling to Barlad to gather data	5	data extracted from BIM model to create the .ifc file in IFC builder. Exporting the data	1
	b) collection and detection of the thermal characteristics of building components (mapping of windows type, wall type…)		1	Information extracted/partially extracted from BIM	1
	c) collection and identification of relevant HVAC characteristics (installed power, type of terminals, …)		0,5	Not included in BIM (same for traditional process)	0,5
	d) data on building operational uses		0	no data available	0
2	**Building geometry creation**				
	a) 2D floorplans reconstruction from on site measurements (needed if detailed and reliable technical drawings are not available)		3	Creation of the IFC file in IFC builder	2
	b) creation of the 3D geometry of the building directly with specific Building Energy Simulation tools		3	creation of the Analytical model using BIM (just minor adjustments may be needed)	1,5
3	**Building thermal characterisation**				
	a) creation of the building components and related libraries (e.g. materials, stratigraphies..)		2	the same as traditional process	2
	b) definition of the thermal zones (uses, internal gains - occupancy, lighting, equipment schedules - temperatures..)		2	the same as traditional process	2
4	**HVAC characterisation**				
	a) creation of the HVAC components (and related libraries)		1	the same as traditional process	1
	b) definition of the systems		2	the same as traditional process	1
	TOTAL TIME REQUIRED		19.5		12
	BIM-to-BEM time reduction compared to current practice: 38%				