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

Deliverable 4.2 – Energy Performance Report – Vitoria demo

Deliverable Report: Final version, issue date on 31.10.2022

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 - VITORIA

Deliverable 4.2 – Energy Performance Report

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Colophon

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1. General information

1.1 Building description

Vitoria democase is a multi-story residential building located in Vitoria-Gasteiz (Spain), in Aldabe Kalea, 26 in a densely urbanized context. The building is characterized by an U-shaped plant with a semi-court in the back of the building. Below the aerial photo of the site with an indicative view of the urban context.

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

The building was built in 1958 and consists of 4 floors with 8 dwellings, 2 dwellings each floor, and a ground floor with the parking lot access and a bar. The constructive characteristics of the building are consistent with the construction period and are characterized by walls with double layer of brick and an air-camera in between cavity wall, reinforced concrete and brick mixed floors and pitched roof with tiles.

Regarding the HVAC systems, the building is characterised by separated heating systems. Each apartment is equipped by a traditional gas boiler for the heating and the domestic hot water production. No cooling systems or mechanical ventilation systems are installed. Following photos shows the external view of the building.

Figure 2: Main façade and back of the building

Following a brief summary of the demo general data

Table 1: General information

General information	
Location	Vitoria-Gasteiz (Spain)
Use category	Residential
Building type	Multi-story building
Construction year	1958
Renovation year	2021
Number of floors	5
Number of apartments/units	8 dwellings, 1 bar

1.2 GIS and environmental data

Vitoria climate data was downloaded directly from the BIM SPEED Platform and the Meeren Weather Service.

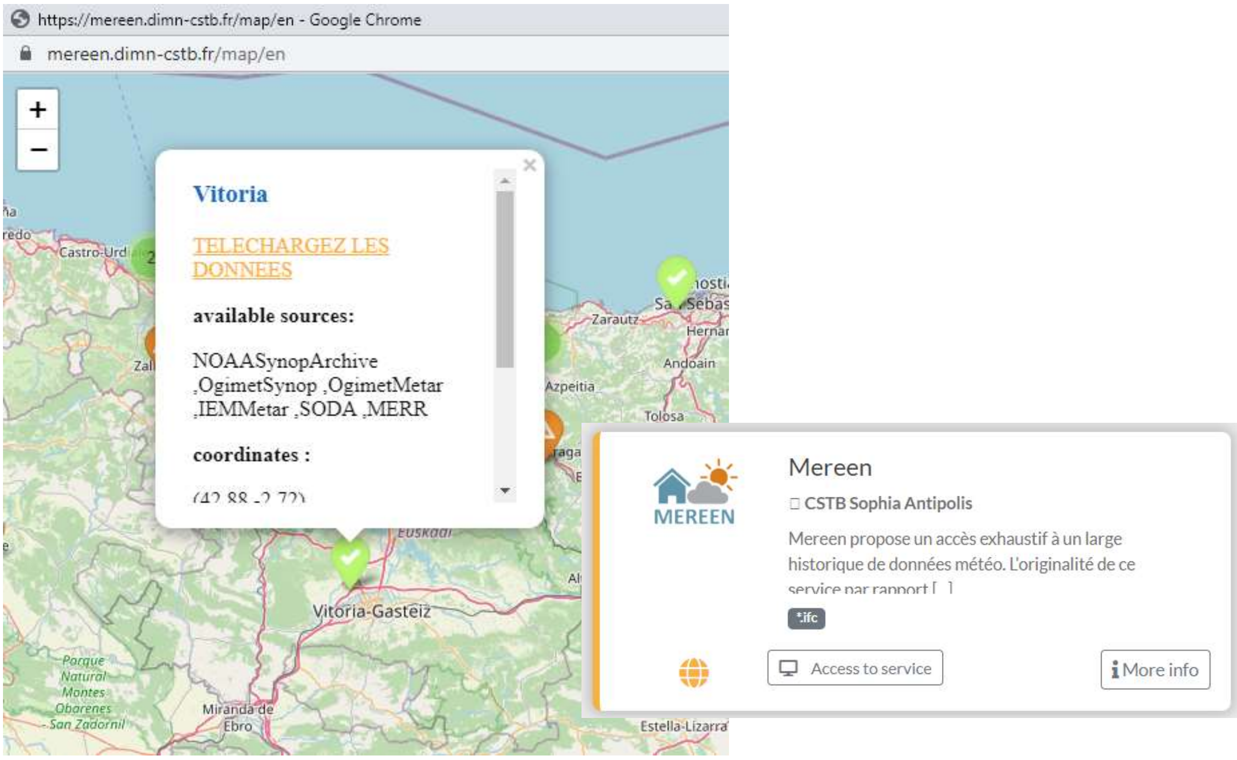


Figure 3: Vitoria's Weather file downloaded from Meeren Weather Service

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

Table 2: General environmental data

General environmental data	
Location	Vitoria-Gasteiz (Spain)
Weather file	ESP_Vitoria.080800_SWEC

Altitude [m]	525
Latitude [degrees]	42°052’0’’ N
Longitude [degrees]	2°41’0’’ W

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

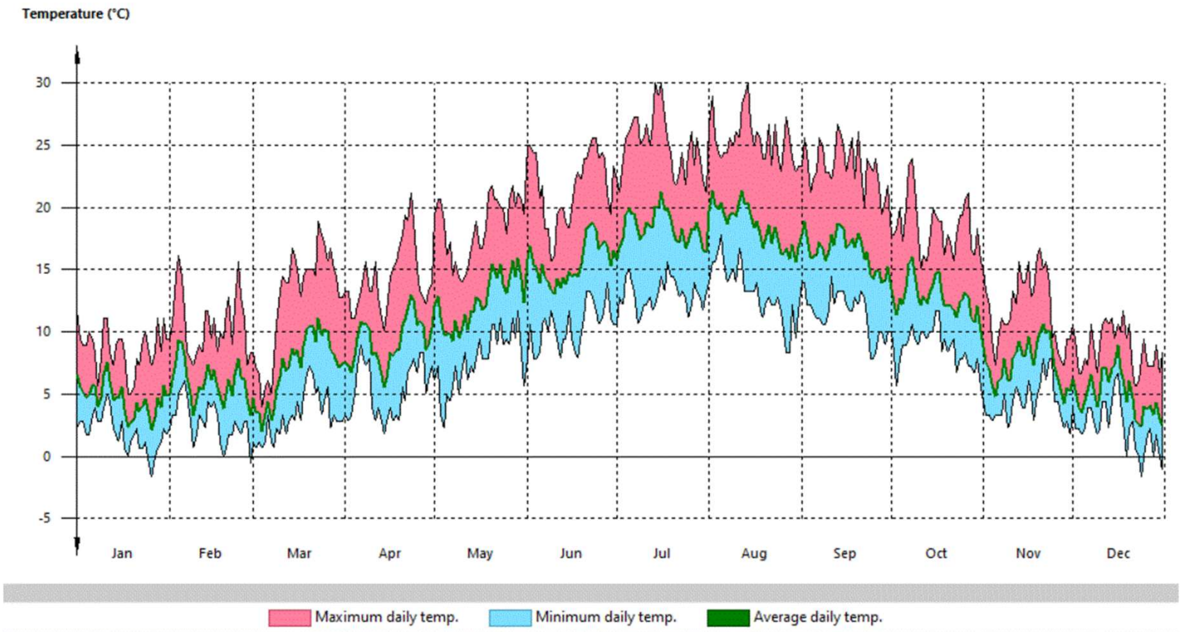


Figure 4: External temperature imported into the BEM model

2. Energy modelling

2.1 BIM-to-BEM procedure and software tools used

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

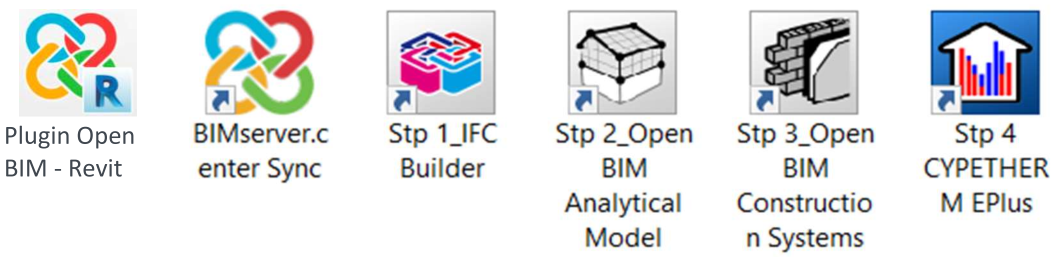


Figure 5: Software tools used to complete the BIM-to-BEM procedure

The BIM model has been developed with Revit software. To integrate the Vitoria BIM into the Open BIM workflow using the IFC standard, a dedicated add-in "Open BIM-Revit" has been used and the Vitoria.ifc file linked to the "BIM SPEED_Vitoria" project on the BIMserver.center platform.

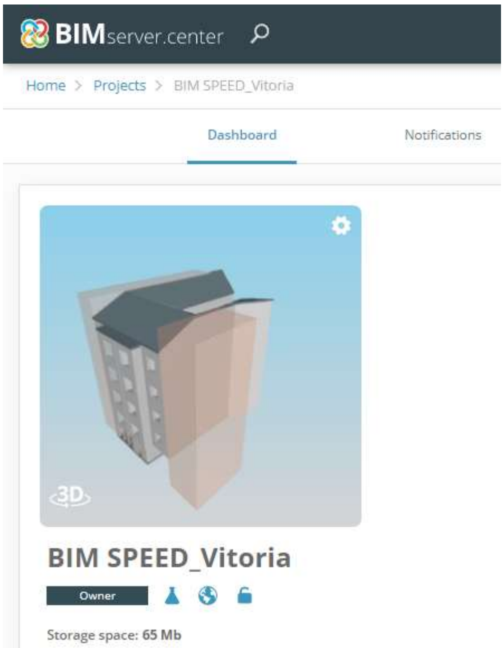


Figure 6: BIM SPEED_Vitoria Project on the BIMserver.center platform

As a result of the Open BIM integration, models of the BIM-to-BEM procedure can be stored and synchronised in the cloud via the BIMserver.center. Starting from the IFC Builder tool, the Vitoria.ifc file has been checked and the internal spaces added.

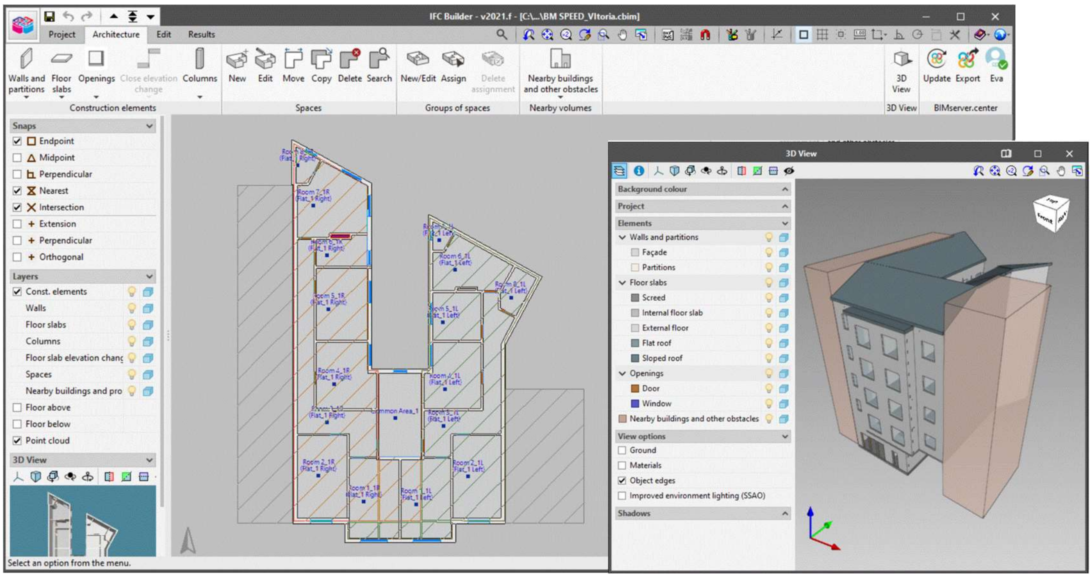


Figure 7: Vitoria demo – IFC Builder

The model has then been exported and synchronized in BIMserver.center and open with the Open BIM Analytical model tool in order 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 11 different thermal zones have been defined and associated to the relevant spaces defined previously with IFC Builder:

- Z01: Commercial Area (ground floor)
- Z01 to Z09: Flats
- Z10: not-heated common stairwell
- Z11: not-heated attic

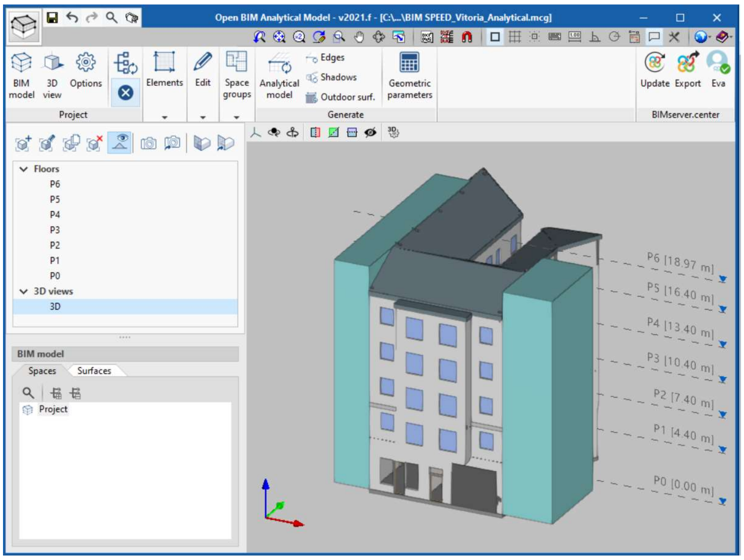


Figure 8: Vitoria demo – Open BIM Analytical Model

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.

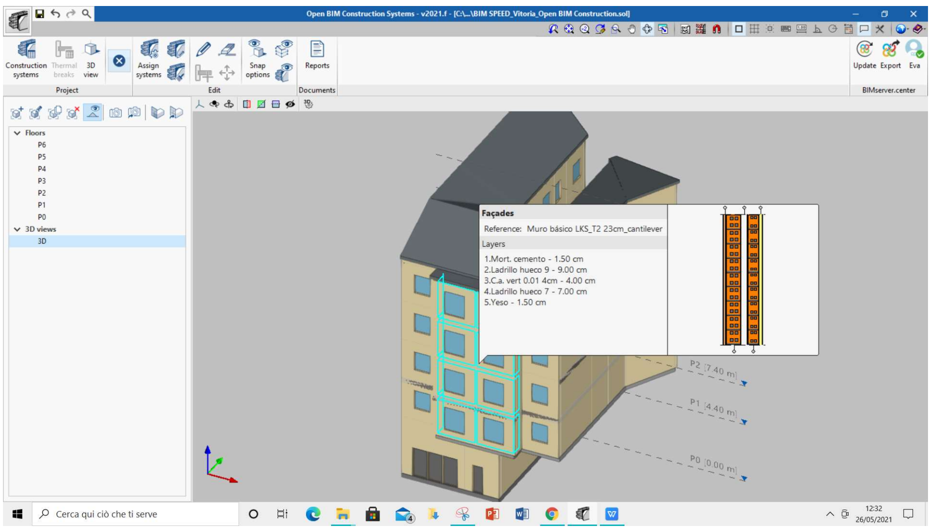


Figure 9: Vitoria demo – Open BIM Construction Systems

As previously done, 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 2.3 paragraph.

2.2 Auditing procedures and data collection

Specific data have been collected both to develop a complete BIM model and suitable BEM. Site surveys on the demo have been carried out by VISESA and specific documents have been investigated to retrieve all the required data to characterise the thermal behaviour of the building. The following images document the digital data acquisition and the results of the activity.

Figure 10: Digital data acquisition

Particularly useful to evaluate the thermal performances of the external walls, it has been the analysis of a thermographic survey conducted in 2019.

Figure 11: Thermographic survey

2.3 Description of BEM's technical features

Vitoria BEM consists of 8 dwellings, 1 commercial unit (bar), common not-heated stairwell, a not-heated attic and a sloped roof. Figure 11 shows the layout of a typical floor while Figure 12 provides the 3D graphical representation of the Vitoria BEM as completed in Cypetherm Eplus.

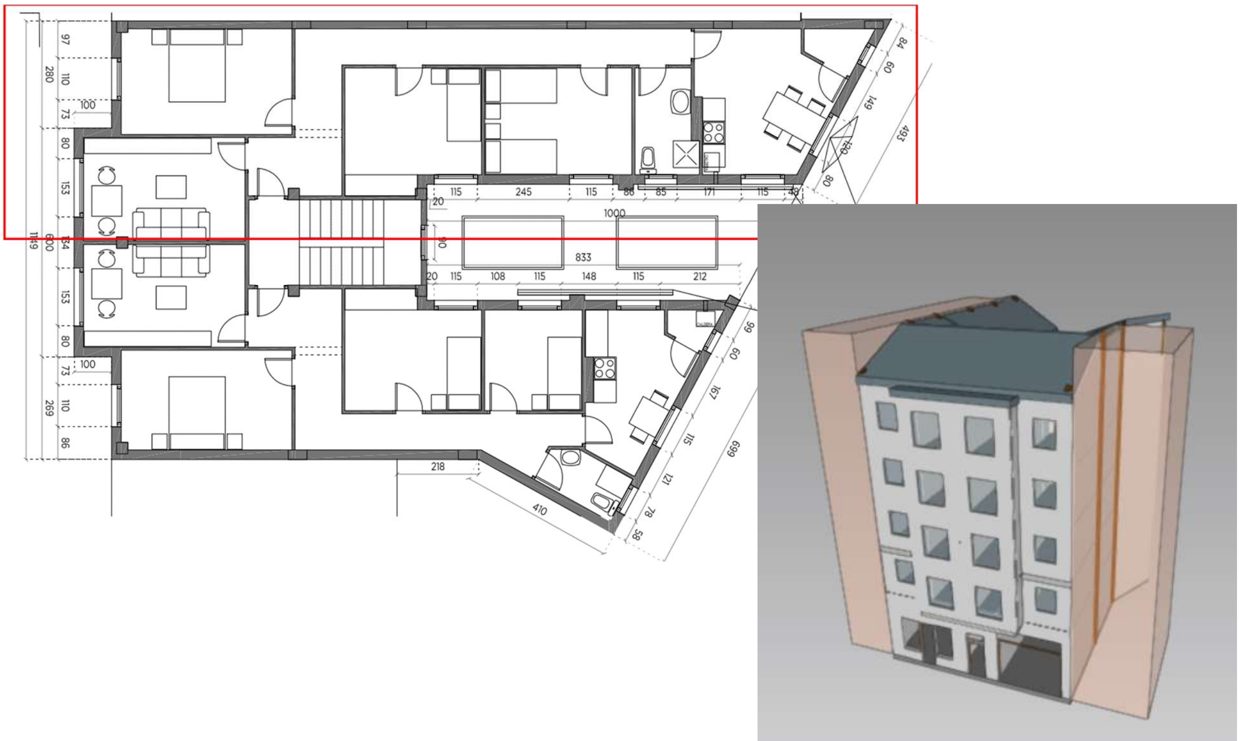


Figure 12: Typical floor layout and 3D graphical representation of the Vitoria BEM

2.3.1 Envelope components and materials

This paragraph summarises the construction systems implemented within the Vitoria BEM to characterise the thermal behaviour of the building. The elements, as well as the single material, have been created and stored in structured libraries. Table 3 summarises all the materials implemented within the BEM.

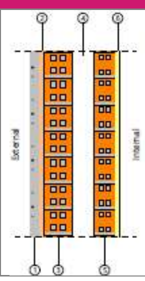
Table 3: Materials

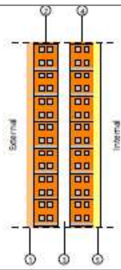
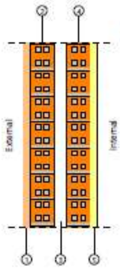
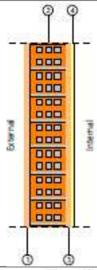
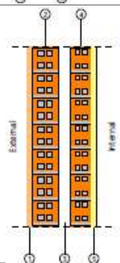
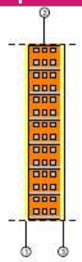
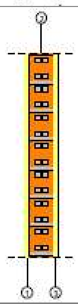
Layers					
Material	e	ρ	λ	RT	Cp
Mort. cemento	2.00	1800.00	0.900	0.02	1000.00
Ladrillo hueco 9	8.00	800.00	0.170	0.47	840.00
Ladrillo hueco 7	8.00	800.00	0.170	0.47	840.00
Yeso	2.00	1200.00	0.350	0.06	1000.00
Plaqueta ceramica	3.00	1000.00	1.300	0.02	1000.00
Mort. cemento	1.50	1000.00	1.400	0.01	1000.00
Ladrillo hueco 9	9.00	1000.00	0.500	0.18	1000.00
Ladrillo hueco 7	7.00	1000.00	0.500	0.14	1000.00
Yeso	1.50	1000.00	0.300	0.05	1000.00
Ladrillo preforado	12.00	1000.00	0.750	0.16	1000.00
Plaquet vitrificada	0.80	1000.00	1.050	0.01	1000.00
Ladrillo hueco 11	11.00	1000.00	0.770	0.14	1000.00
Teja Ceramica	1.00	35.00	1.000	0.01	1000.00
Mort. cemento 5	5.00	2000.00	1.250	0.04	1000.00
Ladrillo hueco 12	12.00	100.00	0.500	0.24	1000.00
Frondosas	1.50	1000.00	0.210	0.07	1000.00
Mort. cemento 5	5.00	1000.00	1.400	0.04	1000.00
Forjado Horme	25.00	1000.00	1.316	0.19	1000.00
Mort. cemento	1.20	1000.00	1.400	0.01	1000.00
Carton-yeso	1.50	1000.00	0.180	0.08	1000.00
Mort cemento	1.20	1000.00	1.200	0.01	1000.00
Frondosas	1.50	2300.00	1.000	0.02	840.00
Mort. cemento 5	5.00	2000.00	1.060	0.05	1000.00
Forjado Horme	25.00	1800.00	1.830	0.14	1000.00
Ground floor - generic	30.00	1000.00	1.429	0.21	1000.00

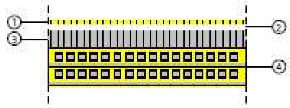
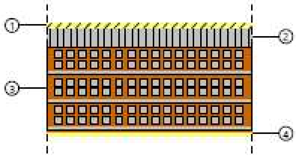
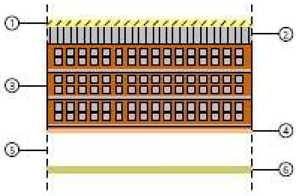
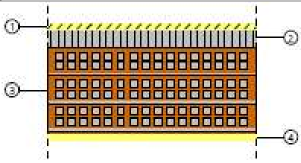
Used abbreviations			
e	*Thickness cm*	RT	*Thermal resistance (m²·K)/W*
ρ	*Density kg/m³*	Cp	*Specific heat J/(kg·K)*
λ	*Thermal conductivity W/(m·K)*		

Within Table 4 all the construction systems created for the Vitoria BEM using the Open BIM Construction Systems tool and stored within a dedicated library linked to the workflow on BIMserver.center have been reported.

Table 4: Construction systems

1.1 Façades		
Muro basico LKS_T1 29 cm		Layer list: 1 - Plaqueta ceramica 3.00 cm 2 - Mort. cemento 1.50 cm 3 - Ladrillo hueco 9 9.00 cm 4 - C.a. vert 0.01 7.00 cm 5 - Ladrillo hueco 7 7.00 cm 6 - Yeso 1.50 cm Thermal transmittance, U: 0.62 W/(m²·K) Total thickness 29.00 cm

Muro basico LKS_T2 23 cm_cantilever		Layer list: 1 - Mort. cemento 2.00 cm 2 - Ladrillo hueco 9 8.00 cm 3 - C.a. vert 0.01 4cm 4.00 cm 4 - Ladrillo hueco 7 8.00 cm 5 - Yeso 2.00 cm Properties Thermal transmittance, U: 0.73 W/(m²·K) Total thickness 24.00 cm
Muro basico LKS_T3 23 cm		Layer list: 1 - Mort. cemento 2.00 cm 2 - Ladrillo hueco 9 8.00 cm 3 - C.a. vert 0.01 4cm 4.00 cm 4 - Ladrillo hueco 7 8.00 cm 5 - Yeso 2.00 cm Properties Thermal transmittance, U: 0.73 W/(m²·K) Total thickness 24.00 cm
Muro basico LKS_T4B 15.8 cm		Layer list: 1 - Mort. cemento 1.50 cm 2 - Ladrillo preforado 12.00 cm 3 - Mort. cemento 1.50 cm 4 - Plaquet vitrificada 0.80 cm Properties Thermal transmittance, U: 2.79 W/(m²·K) Total thickness 15.80 cm
Muro basico LKS_T8 23 cm		Layer list: 1 - Mort. cemento 1.50 cm 2 - Ladrillo hueco 9 9.00 cm 3 - C.a. vert 0.01 4cm 4.00 cm 4 - Ladrillo hueco 7 7.00 cm 5 - Yeso 1.50 cm Properties Thermal transmittance, U: 0.87 W/(m²·K) Total thickness 23.00 cm
1.2 Internal vertical partitioning		
Muro basico LKS_T8 14 cm		Layer list: 1 - Yeso 1.50 cm 2 - Ladrillo hueco 11 11.00 cm 3 - Yeso 1.50 cm Properties Thermal transmittance, U: 1.99 W/(m²·K) Total thickness 14.00 cm
Muro basico LKS_T9 10 cm		Layer list: 1 - Yeso 1.50 cm 2 - Ladrillo hueco 7 7.00 cm 3 - Yeso 1.50 cm Properties Thermal transmittance, U: 2.00 W/(m²·K) Total thickness 10.00 cm
2.1 Roof		

Hollow brick slab with ceramic roof tiles	 Layer list: 1 - Teja Ceramica 1.00 cm 2 - C.a. tech 0.01 2.00 cm 3 - Mort. cemento 5 5.00 cm 4 - Ladrillo hueco 12 12.00 cm Properties: Thermal transmittance, U: 1.37 W/(m²·K) Total thickness 20.00 cm
2.2 Internal horizontal partitioning	
Suelo LKS_T6 32.7cm	 Layer list: 1 - Frondosas 1.50 cm 2 - Mort. cemento 5 5.00 cm 3 - Forjado Horme 25.00 cm 4 - Mort cemento 1.20 cm Properties: Thermal transmittance, U: 1.97 W/(m²·K) Total thickness 32.70 cm
Suelo LKS_T7 44.2cm	 Layer list: 1 - Frondosas 1.50 cm 2 - Mort. cemento 5 5.00 cm 3 - Forjado Horme 25.00 cm 4 - Mort. cemento 1.20 cm 5 - C.a. tech 0.01 - 10 cm 10.00 cm 6 - Carton-yeso 1.50 cm Properties: Thermal transmittance, U: 0.48 W/(m²·K) Total thickness 44.20 cm
Suelo LKS_T10 33cm	 Layer list: 1 - Frondosas 1.50 cm 2 - Mort. cemento 5 5.00 cm 3 - Forjado Horme 25.00 cm 4 - Yeso 2.00 cm Properties: Thermal transmittance, U: 2.19 W/(m²·K) Total thickness 33.50 cm

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

Table 5: Construction systems

3.1 Façade openings	
Interior door Main entrance	Heat transfer coefficient (U): 3.00 W/(m²·K) Absorptance: 0.6
3.2 Windows	
AL single glass	Thermal transmittance, U: 5.72 W/(m²·K) Solar factor, g: 0.950 Opaque fraction, Ff: 0.200
AL double glass	Thermal transmittance, U: 4.12 W/(m²·K) Solar factor, g: 0.970 Opaque fraction, Ff: 0.200
PVC double glass	Thermal transmittance, U: 2.98 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.200
Wood single glass	Thermal transmittance, U: 5.14 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.200

2.3.2 HVAC systems

Regarding the HVAC systems, the building is characterised by separated heating systems. Each apartment is equipped by a traditional boiler for the heating and the domestic hot water production and radiators as terminals. No cooling systems or mechanical ventilation systems are installed. Following table 6 summarises the main parameters of the HVAC systems.

Table 6: HVAC systems

HVAC Systems	Dwelling
Reference name	Traditional Boiler
Year of installation	n.a.
Location of the generator	Internal heated space
Rated capacity [kW]	24
Rated efficiency	60%-80%
Energy fuel	Natural gas
Supply/return [°C]	80/60
Terminal units	Radiators

2.3.3 Occupancy, lighting, equipment and operating patterns

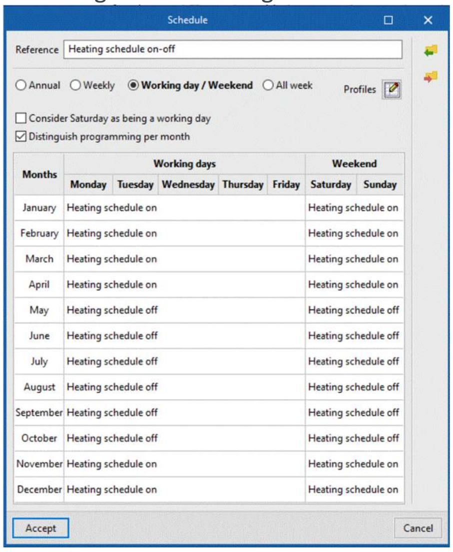
Vitoria BEM has been characterised also under the point of view of the internal gains as summarised in following table 7.

Table 7: Internal gains features

OCCUPIED Space	Ventilation rates	LIGHTING Installed power	EQUIPMENT Installed power	PEOPLE	ACTIVITY level
All Flats	0,5 ACH	5.5 W/mq	5,4 W/mq	30 mq/person	120 W/person

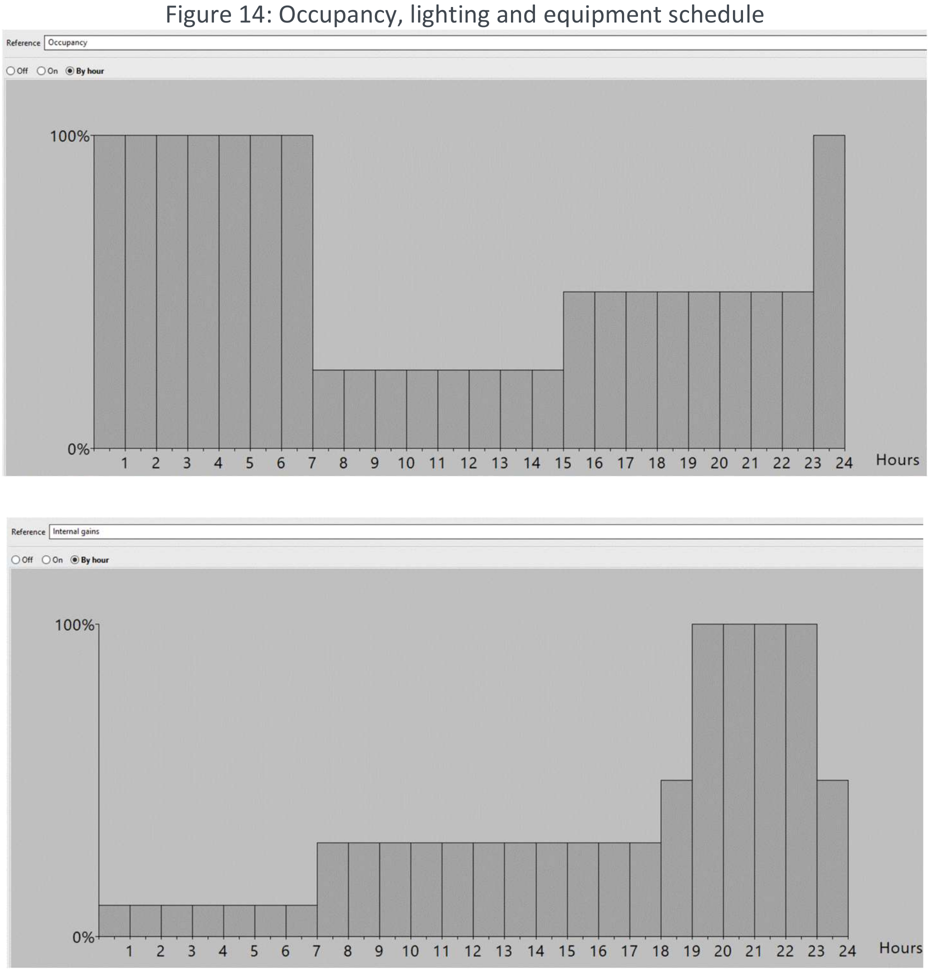
Relevant operating schedules and occupational patterns have been assumed based on standard residential uses and on a few information collected from the users. Following figures show a few of the patterns set for the Vitoria BEM.

Figure 13: Heating schedule



Months	Working days (Monday, Tuesday, Wednesday, Thursday, Friday)	Weekend (Saturday, Sunday)
January	Heating schedule on	Heating schedule on
February	Heating schedule on	Heating schedule on
March	Heating schedule on	Heating schedule on
April	Heating schedule on	Heating schedule on
May	Heating schedule off	Heating schedule off
June	Heating schedule off	Heating schedule off
July	Heating schedule off	Heating schedule off
August	Heating schedule off	Heating schedule off
September	Heating schedule off	Heating schedule off
October	Heating schedule off	Heating schedule off
November	Heating schedule on	Heating schedule on
December	Heating schedule on	Heating schedule on

Figure 14: Occupancy, lighting and equipment schedule



3. BEM calibration

3.1 Calibration methodology applied and results

The automated calibration procedure developed by UNIVMP in Task 3.4 has been applied to the Vitoria BEM in order to check the reliability of the model and the related energy results. The energy consumption used to complete the procedure are those related to 3 energy bills covering a period from 21.11.2019 to 30.06.2020 and documented in the following figure.

Table 8: Real energy consumption for space heating and DHW production

Reporting period	Energy consumption for space heating and DHW (kWh)	Energy consumption for space heating (kWh)
from 21/11/2020 to 13/03/2020	6907	6604
from 14/03/2020 to 20/05/2020	1863	1475
from 21/05/2020 to 30/06/2020	263	-

To simplify and speed up the process, the calibration has been focused on a single apartment (Flat 3R) following 3 main steps:

1. Sensitivity analysis: carried out to identify the most important parameters and discard uninfluential ones from the calibration process;
2. Calibration Phase 1: carried out in terms of indoor air temperatures when the target flat (3R) operated in free-floating conditions (considering the first week of May);
3. Calibration Phase 2: carried out in terms of energy consumption to find the CoP value that provides the best fit for the energy consumption for space heating obtained from bills.

Following table provides the calibration results. Additional details are documented within Deliverable D3.4 "A set of calibrated BEMs for real demonstration cases and proposed standardisation".

Table 9: Calibration results

Reporting period and CV(RMSE)	Experimental	Original BEM	Phase 1 Calibration	Phase 2 Calibration
from 21/11/2019 to 13/03/2020	6604 kWh	8256 kWh	5531 kWh	6482 kWh
from 14/03/2020 to 20/05/2020	1475 kWh	2855 kWh	1724 kWh	2020 kWh
CV(RMSE)	-	37.7%	19.3%	9.8%

The calibrated model has been adopted as the reference BEM model for the actual state and has been then used to develop the interventions.

4. Building energy performance simulation results

4.1 General considerations

The high energy consumption of the building is mainly due to the poor thermal insulation properties of the building envelope both for what concern opaque elements, walls and slabs are not insulated with thermal transmittance varying between 1.23 – 1.73 W/mqK, and windows characterised by thermal transmittance varying between 2.98 – 5.72 W/mqK. Additionally, also the traditional boilers of each flat are not efficient and could be improved.

4.2 Energy KPIs

The following Energy KPI have been calculated 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 Spain) for final energy to primary energy. The table below summarises the primary energy demand related to natural gas and network electricity.

Table 10: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	272.66

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Natural gas	110677.54	188.01	1.195	132259.65	224.67
Electricity obtained from the network	11929.03	20.26	2.368	28247.93	47.99

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 (there is no cooling for the Vitoria demo)

Table 11: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m^{2}year]	85.7
Q_{DHW} [kWh/m^{2}year]	43.5
Q_{TOT} [kWh/m^{2}year]	**129.3**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	Heating	12789.9	5930.4	6785.3	4563.3	38.9	--	--	--	--	72.9	9548.8	10744.1	50473.6	85.7
	DHW	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	TOTAL	14967.0	7896.8	8962.4	6670.2	2216.0	2106.9	2177.1	2177.1	2106.9	2250.0	11655.7	12921.3	76107.4	129.3

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 12: BS.TEC Total Energy Consumption

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	**12789.9**	**5930.4**	**6785.3**	**4563.3**	**38.9**	**--**	**--**	**--**	**--**	**72.9**	**9548.8**	**10744.1**	**50473.6**	**85.7**
	DHW	**2177.1**	**1966.4**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**25633.8**	**43.5**
	TOTAL	**14967.0**	**7896.8**	**8962.4**	**6670.2**	**2216.0**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2250.0**	**11655.7**	**12921.3**	**76107.4**	**129.3**
Natural gas (f_{cep} = 1.189)	EF_{heat}	16347.5	7467.1	8546.1	5726.4	64.8	--	--	--	--	121.4	12120.9	13676.3	64070.6	108.8
	EP_{heat}	19535.2	8923.2	10212.6	6843.0	77.5	--	--	--	--	145.1	14484.4	16343.2	76564.4	130.1
	$EP_{nr,heat}$	**19437.6**	**8878.6**	**10161.6**	**6808.8**	**77.1**	**--**	**--**	**--**	**--**	**144.4**	**14412.0**	**16261.4**	**76181.5**	**129.4**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	
	EF_{dhw}	3958.4	3575.3	3958.4	3830.7	3958.4	3830.7	3958.4	3958.4	3830.7	3958.4	3830.7	3958.4	46606.9	79.2
	EP_{dhw}	4730.3	4272.5	4730.3	4577.7	4730.3	4577.7	4730.3	4730.3	4577.7	4730.3	4577.7	4730.3	55695.3	94.6
	$EP_{nr,dhw}$	**4706.6**	**4251.2**	**4706.6**	**4554.8**	**4706.6**	**4554.8**	**4706.6**	**4706.6**	**4554.8**	**4706.6**	**4554.8**	**4706.6**	**55416.8**	**94.1**
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}	1013.2	915.1	1013.2	980.5	1013.2	980.5	1013.2	1013.2	980.5	1013.2	980.5	1013.2	11929.0	20.3
	EP_{light}	2399.1	2167.0	2399.1	2321.7	2399.1	2321.7	2399.1	2399.1	2321.7	2399.1	2321.7	2399.1	28247.9	48.0
	$EP_{nr,light}$	**1979.8**	**1788.2**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**23310.2**	**39.6**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**21319.0**	**11957.6**	**13517.7**	**10537.6**	**5036.4**	**4811.2**	**4971.5**	**4971.5**	**4811.2**	**5093.0**	**16932.0**	**18647.8**	**122606.6**	**208.3**
	C_{ep}	**26664.7**	**15362.7**	**17342.1**	**13742.5**	**7206.9**	**6899.4**	**7129.4**	**7129.4**	**6899.4**	**7274.6**	**21383.9**	**23472.6**	**160507.6**	**272.7**
	$C_{ep,nr}$	**26124.0**	**14917.9**	**16848.0**	**13279.5**	**6763.5**	**6470.7**	**6686.4**	**6686.4**	**6470.7**	**6830.8**	**20882.7**	**22947.8**	**154908.6**	**263.1**

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.

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	130.1
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	48.0
EP_{dhw}[kWh/m²]	94.6
EP_{TOT}[kWh/m²]	**272.7**

5. Building renovation scenarios

To perform and assess multiple energy simulations for building renovation scenarios, the CYPETHERM EPlus has been used taking the Calibrated BEM baseline as a reference. The interventions have been modelled changing the relevant parameters within the Calibrated Model.

5.1 Renovation scenarios proposed

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

Table 13: Overview of the Vitoria Renovation Scenarios

	External Wall insulation	Roof insulation	Windows replacement	Heating System replacement	Floor insulation	Additional Energy Source
Scenario 01	ETICS	+Styrodur	A 70 Hindged	District Heating	-	-
Scenario 02	ETICS	+Styrodur	-	District Heating	-	-
Scenario 03	-	+Styrodur	A 70 Hindged	-	+Rockwool	Photovoltaic

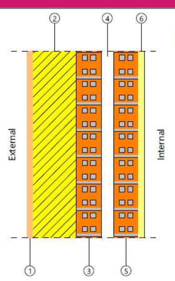
5.2 Scenario 1: description and results

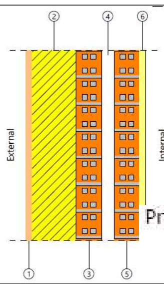
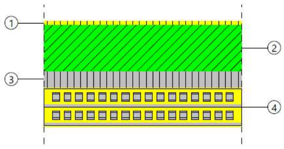
In scenario 1, the following interventions has been analysed:

1. An insulation layer made up of EPS 032 (thickness 0.14m and thermal conductivity 0.032 W/mK) was added on the external side of the external walls.
2. An insulation layer made up of XPS Styrodur (thickness 0.14m and thermal conductivity 0.029 W/mk) was added on the external side of the roof.
3. All the existing windows were replaced with new pvc windows (A 70 Hinged PVC) with a glazing heat transfer coefficient Uw of 0.9 W/m^{2}K.
4. The heating system of the model is also upgraded from a boiler system to district heating (both for heating and for the DHW production).

The following table summarises the new construction systems.

Table 14: Construction systems

1.1 Façades		
Muro basico LKS_T2 23 cm_cantilever + external insulation		Layer list: 1 - Mort. cemento 2.00 cm 2 - EPS 032 14.00 cm 3 - Ladrillo hueco 9 8.00 cm 4 - C.a. vert 0.01 4cm 4.00 cm 5 - Ladrillo hueco 7 8.00 cm 6 - Yeso 2.00 cm Thermal transmittance, U: 0.17 W/(m²·K) Total thickness 38.00 cm

Muro basico LKS_T3 23 cm + external insulation	 Layer list: 1 - Mort. cemento 2.00 cm 2 - EPS 032 14.00 cm 3 - Ladrillo hueco 9 8.00 cm 4 - C.a. vert 0.01 4cm 4.00 cm 5 - Ladrillo hueco 7 8.00 cm 6 - Yeso 2.00 cm Properties Thermal transmittance, U: 0.73 W/(m²·K) Total thickness 24.00 cm
2.1 Roof	
Hollow brick slab with ceramic roof tiles + external insulation	 Layer list: 1 - Teja Ceramica 1.00 cm 2 - Inusulating layer STYRODUR 14.00 cm 3 - Mort. cemento 5 5.00 cm 4 - Ladrillo hueco 12 12.00 cm Properties Thermal transmittance, U: 0.19 W/(m²·K) Total thickness 32.00 cm
3.1 Windows	
New windows	Uw=0.9 W/m²K

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 15: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	146.24

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Coal	53353.74	90.63	1.084	57835.45	98.25
Electricity obtained from the network	11929.03	20.26	2.368	28247.93	47.99

where:

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

Table 16: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	47.1
Q_{DHW} [kWh/m²year]	43.5
Q_{TOT} [kWh/m²year]	**90.6**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	7351.9	3049.6	3791.1	2336.7	0.0	--	--	--	--	0.2	5191.2	5999.1	27719.9	47.1
	DHW	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	TOTAL	9529.1	5016.0	5968.2	4443.6	2177.1	2106.9	2177.1	2177.1	2106.9	2177.3	7298.1	8176.2	53353.7	90.6

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

Table 17: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	51.0
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	48.0
EP_{dhw}[kWh/m²]	47.2
EP_{TOT}[kWh/m²]	**146.2**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	**7351.9**	**3049.6**	**3791.1**	**2336.7**	**0.0**	**--**	**--**	**--**	**--**	**0.2**	**5191.2**	**5999.1**	**27719.9**	**47.1**
	DHW	**2177.1**	**1966.4**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**25633.8**	**43.5**
	TOTAL	**9529.1**	**5016.0**	**5968.2**	**4443.6**	**2177.1**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2177.3**	**7298.1**	**8176.2**	**53353.7**	**90.6**
Coal (f_{ep} = 1.082)	EF_{heat}	7351.9	3049.6	3791.1	2336.7	0.0	--	--	--	--	0.2	5191.2	5999.1	27719.9	47.1
	EP_{heat}	7969.5	3305.8	4109.5	2533.0	0.0	--	--	--	--	0.2	5627.3	6503.0	30048.4	51.0
	$EP_{nr,heat}$	**7954.4**	**3299.5**	**4101.7**	**2528.2**	**0.0**	**--**	**--**	**--**	**--**	**0.2**	**5616.6**	**6490.7**	**29991.3**	**50.9**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	
	EF_{dhw}	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	EP_{dhw}	2360.0	2131.6	2360.0	2283.9	2360.0	2283.9	2360.0	2360.0	2283.9	2360.0	2283.9	2360.0	27787.1	47.2
	$EP_{nr,dhw}$	**2355.5**	**2127.6**	**2355.5**	**2279.5**	**2355.5**	**2279.5**	**2355.5**	**2355.5**	**2279.5**	**2355.5**	**2279.5**	**2355.5**	**27734.3**	**47.1**
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}	1013.2	915.1	1013.2	980.5	1013.2	980.5	1013.2	1013.2	980.5	1013.2	980.5	1013.2	11929.0	20.3
	EP_{light}	2399.1	2167.0	2399.1	2321.7	2399.1	2321.7	2399.1	2399.1	2321.7	2399.1	2321.7	2399.1	28247.9	48.0
	$EP_{nr,light}$	**1979.8**	**1788.2**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**23310.2**	**39.6**
Auto-consumed electricity (f_{ep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**10542.2**	**5931.2**	**6981.4**	**5424.1**	**3190.3**	**3087.4**	**3190.3**	**3190.3**	**3087.4**	**3190.5**	**8278.6**	**9189.4**	**65282.8**	**110.9**
	C_{ep}	**12728.6**	**7604.4**	**8868.7**	**7138.6**	**4759.2**	**4605.6**	**4759.1**	**4759.1**	**4605.6**	**4759.3**	**10232.9**	**11262.2**	**86083.4**	**146.2**
	$C_{ep,nr}$	**12289.6**	**7215.2**	**8437.0**	**6723.7**	**4335.3**	**4195.4**	**4335.3**	**4335.3**	**4195.4**	**4335.5**	**9812.0**	**10825.9**	**81035.8**	**137.7**

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.*

BS.TES: Total Energy savings

Table 18: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 01	SAVING
EP_{heat}[kWh/m²]	130.1	51.0	79.1
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	48.0	48.0	0
EP_{dhw}[kWh/m²]	94.6	47.2	47.4
EP_{TOT}[kWh/m²]	**272.7**	**146.2**	**126.5**

5.3 Scenario 2: description and results

Scenario 2 is similar to scenario 1 with the external insulation of the external walls and roof and the replacement of the heating system. Only difference is that the windows are kept as the pre-existing ones.

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 19: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	161.16

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Coal	61456.06	104.40	1.084	66618.37	113.17
Electricity obtained from the network	11929.03	20.26	2.368	28247.93	47.99

where:

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

Table 20: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m^{2}year]	60.9
Q_{DHW} [kWh/m^{2}year]	43.5
Q_{TOT} [kWh/m^{2}year]	**104.4**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	Heating	9588.1	4025.6	4605.0	2788.8	4.7	--	--	--	--	1.9	6895.8	7912.4	35822.2	60.9
	DHW	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	TOTAL	11765.2	5992.0	6782.1	4895.7	2181.8	2106.9	2177.1	2177.1	2106.9	2179.0	9002.7	10089.5	61456.1	104.4

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

Table 21: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m^2]	66.0
EP_{cool}[kWh/m^2]	Cooling not present
EP_{light}[kWh/m^2]	48.0
EP_{dhw}[kWh/m^2]	47.2
EP_{TOT}[kWh/m^2]	**161.2**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	**9588.1**	**4025.6**	**4605.0**	**2788.8**	**4.7**	--	--	--	--	**1.9**	**6895.8**	**7912.4**	**35822.2**	**60.9**
	DHW	**2177.1**	**1966.4**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**25633.8**	**43.5**
	TOTAL	**11765.2**	**5992.0**	**6782.1**	**4895.7**	**2181.8**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2179.0**	**9002.7**	**10089.5**	**61456.1**	**104.4**
Coal (f_{cep} = 1.082)	EF_{heat}	9588.1	4025.6	4605.0	2788.8	4.7	--	--	--	--	1.9	6895.8	7912.4	35822.2	60.9
	EP_{heat}	10393.5	4363.8	4991.8	3023.1	5.0	--	--	--	--	2.0	7475.1	8577.0	38831.3	66.0
	$EP_{nr,heat}$	**10373.8**	**4355.5**	**4982.3**	**3017.3**	**5.0**	--	--	--	--	**2.0**	**7460.9**	**8560.7**	**38757.5**	**65.8**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	EP_{dhw}	2360.0	2131.6	2360.0	2283.9	2360.0	2283.9	2360.0	2360.0	2283.9	2360.0	2283.9	2360.0	27787.1	47.2
	$EP_{nr,dhw}$	**2355.5**	**2127.6**	**2355.5**	**2279.5**	**2355.5**	**2279.5**	**2355.5**	**2355.5**	**2279.5**	**2355.5**	**2279.5**	**2355.5**	**27734.3**	**47.1**
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}	1013.2	915.1	1013.2	980.5	1013.2	980.5	1013.2	1013.2	980.5	1013.2	980.5	1013.2	11929.0	20.3
	EP_{light}	2399.1	2167.0	2399.1	2321.7	2399.1	2321.7	2399.1	2399.1	2321.7	2399.1	2321.7	2399.1	28247.9	48.0
	$EP_{nr,light}$	**1979.8**	**1788.2**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**23310.2**	**39.6**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**12778.4**	**6907.1**	**7795.2**	**5876.2**	**3194.9**	**3087.4**	**3190.3**	**3190.3**	**3087.4**	**3192.1**	**9983.2**	**11102.7**	**73385.1**	**124.7**
	C_{ep}	**15152.7**	**8662.3**	**9750.9**	**7628.7**	**4764.2**	**4605.6**	**4759.1**	**4759.1**	**4605.6**	**4761.2**	**12080.7**	**13336.2**	**94866.3**	**161.2**
	$C_{ep,nr}$	**14709.1**	**8271.2**	**9317.6**	**7212.8**	**4340.3**	**4195.4**	**4335.3**	**4335.3**	**4195.4**	**4337.3**	**11656.3**	**12896.0**	**89802.0**	**152.5**

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.*

BS.TES: Total Energy savings

Table 22: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	**Scenario 02**	**SAVING**
EP_{heat}[kWh/m²]	130.1	66.0	64.1
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	48.0	48.0	0
EP_{dhw}[kWh/m²]	94.6	47.2	47.4
EP_{TOT}[kWh/m²]	**272.7**	**161.2**	**111.5**

5.4 Scenario 3: description and results

In scenario 3, the following interventions has been analysed:

1. An insulation layer made up of XPS Styrodur (thickness 0.14m and thermal conductivity 0.029 W/mk) was added on the external side of the roof (same as scenario 1 and 2).
2. All the existing windows were replaced with new windows with A70 Hinged PVC) with a glazing heat transfer coefficient of 0.9 W/m²K (same as scenario 1).

3. An insulation layer made up of rockwool (thickness 0.08m and thermal conductivity 0.034 W/mk) was added on the lower side of the external floor of the first floor.
4. Photovoltaic Solar panels were added with a total power installed of 4.5 kWp. They have a potential of producing 5540.1 kWh/year.

No insulation of the external walls has been analysed as well as the replacement of the heating and DHW systems.

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 23: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	13.9

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Natural gas	93169.65	158.27	1.195	111337.73	189.13
Electricity obtained from the network	-43561.07	-74.00	2.368	-103152.62	-175.23
Electricity produced on site (renewable)	55490.10	94.26	1.000	55490.10	94.26

where:

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.

('Natural gas' and 'Electricity obtained from the network' have to be considered – 'Electricity produced on site' is already included in the results of the 'Electricity obtained from the network')

BS.TED: Total Energy Demand

Table 24: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m^{2}year]	60.4
Q_{DHW} [kWh/m^{2}year]	43.5
Q_{TOT} [kWh/m^{2}year]	**104**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	9114.6	4036.3	4907.1	3213.9	22.6	--	--	--	--	44.6	6681.7	7544.4	35565.4	60.4
	DHW	2177.1	1966.4	2177.1	2106.9	2177.1	2106.9	2177.1	2177.1	2106.9	2177.1	2106.9	2177.1	25633.8	43.5
	TOTAL	11291.8	6002.7	7084.2	5320.8	2199.7	2106.9	2177.1	2177.1	2106.9	2221.7	8788.6	9721.6	61199.2	104.0

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

Table 25: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m^2]	94.5
EP_{cool}[kWh/m^2]	Cooling not present
EP_{light}[kWh/m^2]	48.0
EP_{dhw}[kWh/m^2]	94.6
EP_{solar}[kWh/m^2]	-223.2
EP_{TOT}[kWh/m^2]	**13.9**

		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 = 588.68 m²; V = 1572.35 m³)															
Energy demand	**Heating**	**9114.6**	**4036.3**	**4907.1**	**3213.9**	**22.6**	--	--	--	--	**44.6**	**6681.7**	**7544.4**	**35565.4**	**60.4**
	DHW	**2177.1**	**1966.4**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2177.1**	**2106.9**	**2177.1**	**25633.8**	**43.5**
	TOTAL	**11291.8**	**6002.7**	**7084.2**	**5320.8**	**2199.7**	**2106.9**	**2177.1**	**2177.1**	**2106.9**	**2221.7**	**8788.6**	**9721.6**	**61199.2**	**104.0**
Natural gas (f_{cep} = 1.189)	EF_{heat}	11978.1	5259.5	6408.8	4172.3	28.5	--	--	--	--	56.3	8759.6	9899.5	46562.7	79.1
	EP_{heat}	14313.9	6285.2	7658.5	4985.9	34.1	--	--	--	--	67.3	10467.7	11829.9	55642.4	94.5
	$EP_{nr,heat}$	**14242.3**	**6253.7**	**7620.2**	**4961.0**	**33.9**	--	--	--	--	**66.9**	**10415.4**	**11770.7**	**55364.2**	**94.0**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	3958.4	3575.3	3958.4	3830.7	3958.4	3830.7	3958.4	3958.4	3830.7	3958.4	3830.7	3958.4	46606.9	79.2
	EP_{dhw}	4730.3	4272.5	4730.3	4577.7	4730.3	4577.7	4730.3	4730.3	4577.7	4730.3	4577.7	4730.3	55695.3	94.6
	$EP_{nr,dhw}$	**4706.6**	**4251.2**	**4706.6**	**4554.8**	**4706.6**	**4554.8**	**4706.6**	**4706.6**	**4554.8**	**4706.6**	**4554.8**	**4706.6**	**55416.8**	**94.1**
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}	1013.2	915.1	1013.2	980.5	1013.2	980.5	1013.2	1013.2	980.5	1013.2	980.5	1013.2	11929.0	20.3
	EP_{light}	2399.1	2167.0	2399.1	2321.7	2399.1	2321.7	2399.1	2399.1	2321.7	2399.1	2321.7	2399.1	28247.9	48.0
	$EP_{nr,light}$	**1979.8**	**1788.2**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**1979.8**	**1915.9**	**1979.8**	**1915.9**	**1979.8**	**23310.2**	**39.6**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	-55490.1	-94.3
	EP	--	--	--	--	--	--	--	--	--	--	--	--	-131400.6	-223.2
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	-108431.7	-184.2
	$C_{ef,total}$	**16949.7**	**9750.0**	**11380.4**	**8983.5**	**5000.1**	**4811.2**	**4971.5**	**4971.5**	**4811.2**	**5027.8**	**13570.8**	**14871.0**	**49608.6**	**84.3**
	C_{ep}	**21443.3**	**12724.6**	**14788.0**	**11885.3**	**7163.5**	**6899.4**	**7129.4**	**7129.4**	**6899.4**	**7196.7**	**17367.2**	**18959.3**	**8185.1**	**13.9**
	$C_{ep,nr}$	**20928.7**	**12293.1**	**14306.6**	**11431.7**	**6720.3**	**6470.7**	**6686.4**	**6686.4**	**6470.7**	**6753.3**	**16886.1**	**18457.1**	**25659.5**	**43.6**

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.

BS.TES: Total Energy savings

Table 26: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 03	SAVING
EP_{heat}[kWh/m²]	130.1	94.5	35.6
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	48.0	48.0	0
EP_{dhw}[kWh/m²]	94.6	94.6	0
EP_{solar}[kWh/m²]	0	-223.2	223.2
EP_{TOT}[kWh/m²]	**272.7**	**13.9**	**258.8**

6. Time reduction evaluation

Following table shows the results of the time reduction for the Vitoria 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 27: 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)		3	Information extracted directly from BIM	0
	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)	1
	d) data on building operational uses		0,5	Not included in BIM (same for traditional process)	0,5
2	**Building geometry creation**				
	a) 2D floorplans reconstruction from on site measurements (needed if detailed and reliable technical drawings are not available)		2	Not needed - geometrical information extracted directly from BIM	0
	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..)		1	the same as traditional process	1
	b) definition of the thermal zones (uses, internal gains - occupancy, lighting, equipment schedules - temperatures..)		1	the same as traditional process	1
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	2
	TOTAL TIME REQUIRED		**15.5**		**9**
BIM-to-BEM time reduction compared to current practice: 42%					