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

Deliverable 4.2 – Energy Performance Report – Frigento demo

Deliverable Report: Final version, issue date on XXXXX

BIM-SPEED

Harmonised Building Information Speedway for Energy-Efficient Renovation

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ENERGY REPORT - FRGENTO

Deliverable 4.2 – Energy Performance Report

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Colophon

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1. General information

1.1 Building description

Frigento democase is a residential building called “Palazzo Testa Cipriano” located in the historical centre of Frigento (Italy) in a densely urbanized context, between via Duomo, via San Giovanni and vico dietro Campanile. The building is characterized by a rectangular plant and by a compact volume with a central court. 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 original building construction year dates back to 1600 with subsequent restoration actions, one of the latest in 1783, date impress on the main entrance. Due to the cultural value of the whole historical centre, the building is protected by the Cultural Heritage Office. In 1980 the building was subjected to a consistent consolidation intervention, mostly addressed to the first floor, due to damages caused by an earthquake. The demo building consists of 2 apartments (Flat “Testa” and Flat “Cipriano”) and 2 floors (ground floor and first floor) and it is characterized by stone-brick masonry walls and reinforced concrete and brick mixed floor and roof. In addition to the 2 apartments, on the ground floor, there are also a few unheated rooms. Regarding the HVAC systems, the building is characterised by 2 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 entrance – Via Duomo and internal court

Figure 3: Lateral façade – Via San Giovanni

Following a brief summary of the demo general data

Table 1: General information

General information	
Location	Frigento (Italy)
Use category	Residential
Building type	Double family house
Construction year	1600 – 1783 (original building)
Renovation year	1980 (1^{st} floor consistent consolidation)
Number of floors	2
Number of apartments/units	2

1.2 GIS and environmental data

Frigento is not included in the available weather file list of EnergyPlus. The results of a climatic analysis on similar locations, shown in table 2, demonstrate a close affinity with the location of Potenza that is adopted for the BEM.

Table 2: Average external temperature - comparison

Temp. Average °C												
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Frigento	3,3	3,8	5,8	8,8	13,4	17,3	20,4	20,5	17,2	12,4	8,1	4,5
Campobasso	4,1	4,9	6,8	9,9	14,6	18,4	21,3	21,5	17,9	13,3	9,1	5,4
Ravenna	3,1	5,1	8,5	12,5	16,8	20,6	23,1	22,8	19,8	14,7	9	4,2
Perugia	3,8	5	7,2	10,7	15,1	19,1	22	21,7	18,3	13,6	8,9	5,4
Potenza	3,8	4,3	6,4	9,4	13,9	17,7	20,4	20,8	17,4	12,7	8,7	5,4
Udine	3,1	4,5	7,9	12	16,6	20,1	22,3	21,8	18,5	13,6	8,2	4,4

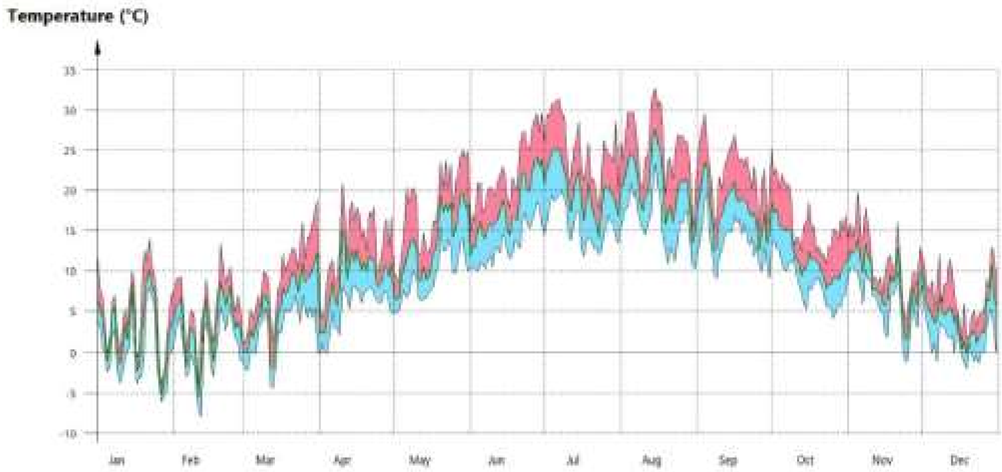


Figure 4: External temperature imported into the BEM model

Following a brief summary of the climate data of the Italian demo

Table 3: General environmental data

General environmental data	
Location	Frigento (Italy)
Weather file	ITA_Potenza.163000_IGDG
Altitude [m]	911
Latitude [degrees]	41°00’45.29’’ N
Longitude [degrees]	15°05’58.70’’ E
Undistributed temp. of the soil [°C]	2
Network water temperature [°C]	2

2. Energy modelling

2.1 BIM-to-BEM procedure and software tools used

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

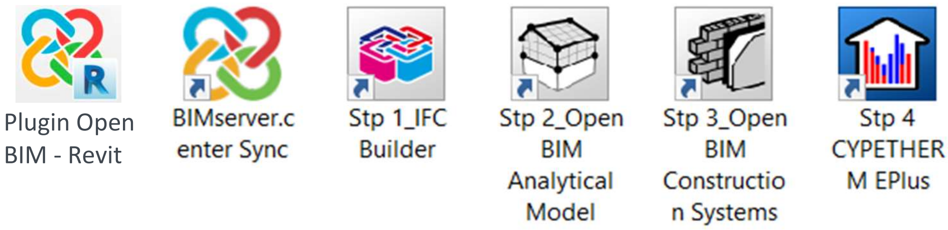


Figure 5: Software tools used to complete the BIM-to-BEM procedure

The BIM model has been developed with Revit software. To integrate the Frigento BIM into the Open BIM workflow using the IFC standard, a dedicated add-in “Open BIM-Revit” has been used and the Frigento.ifc file linked to the “BIM SPEED_Frigento_V0” 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 Frigento.ifc file has been checked and the internal spaces added.

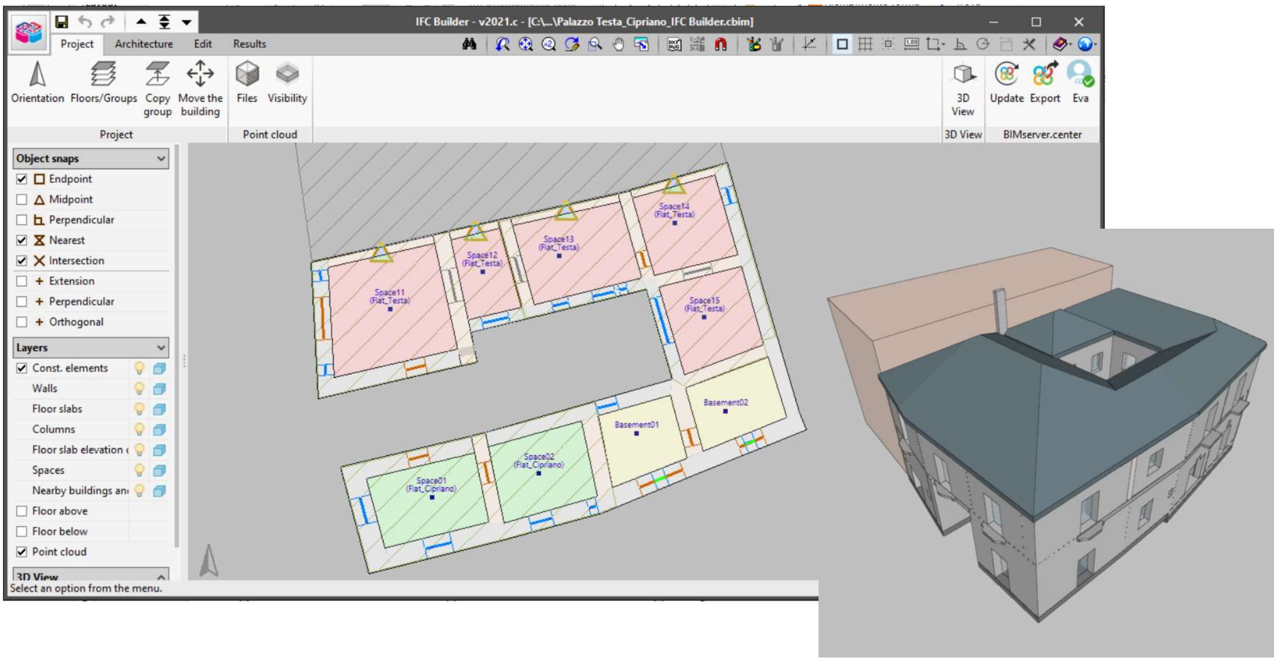


Figure 6: Frigento demo – IFC Builder

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 4 different thermal zones have been defined and associated to the relevant spaces defined previously with IFC Builder:

- Flat Testa
- Flat Cipriano
- Not heated basement
- Not heated Attic.

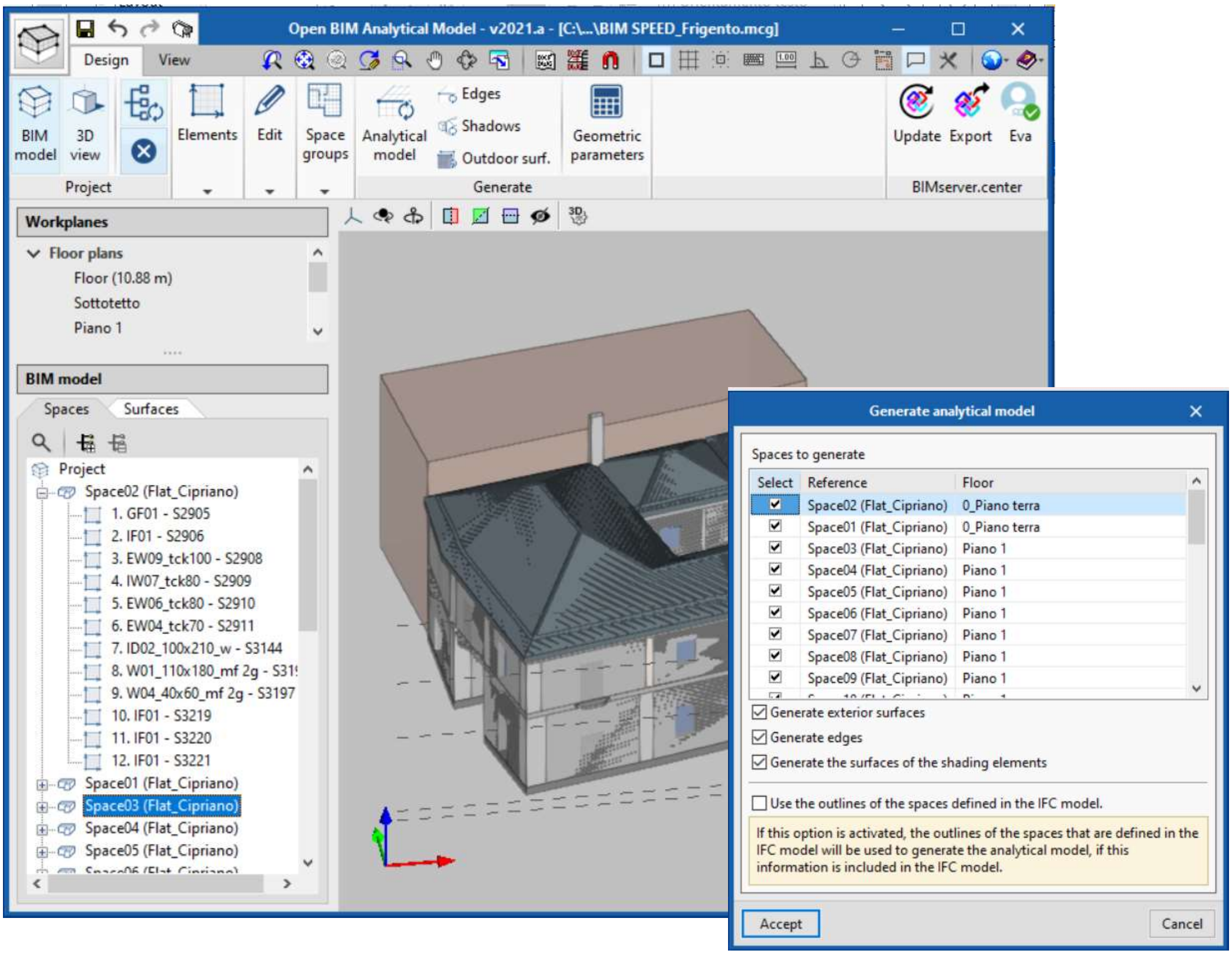


Figure 7: Frigento demo – Open BIM Analytical Model

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.

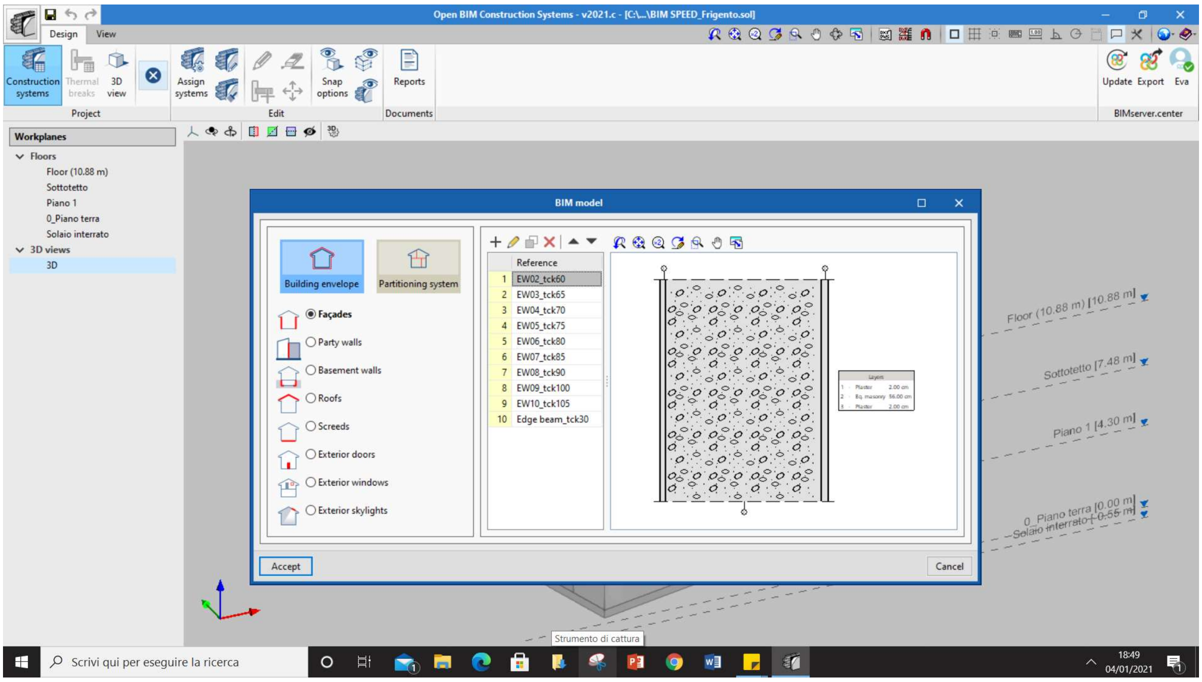


Figure 8: Frigento demo – Open BIM Construction Systems

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 STRESS and specific documents have been investigated to retrieve all the required data to characterise the thermal behaviour of the building. Particularly useful to evaluate the thermal performances of the external walls, it has been the analysis of a thermographic survey conducted in 2015 and available from the ower. Thermal transmittance has been measured with the thermal imaging camera model Testo 435-2 and LSI Lastem tool as reported in the following images, in line with the standard ISO 9869.

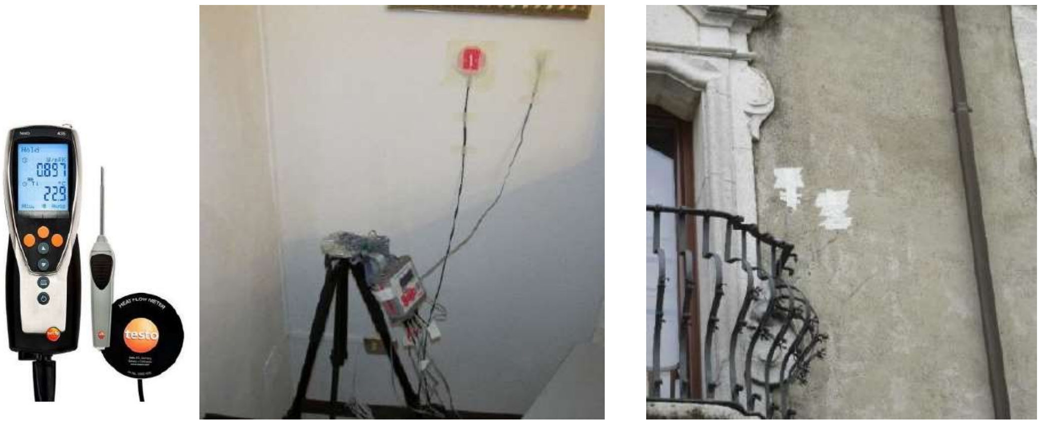


Figure 9: Thermographic survey

2.3 Description of BEM's technical features

Frigento BEM consists of 2 apartments: Flat "Testa" and Flat "Cipriano" located on 2 floors (ground floor and first floor) with a not-heated attic and a sloped roof. Figure 10 shows layouts of the 2 floors while figure 11 provide the 3D graphical representation of the Frigento BEM as completed in Cypetherm Eplus.

Figure 10: Ground floor (left image) and 1st floor (right image)

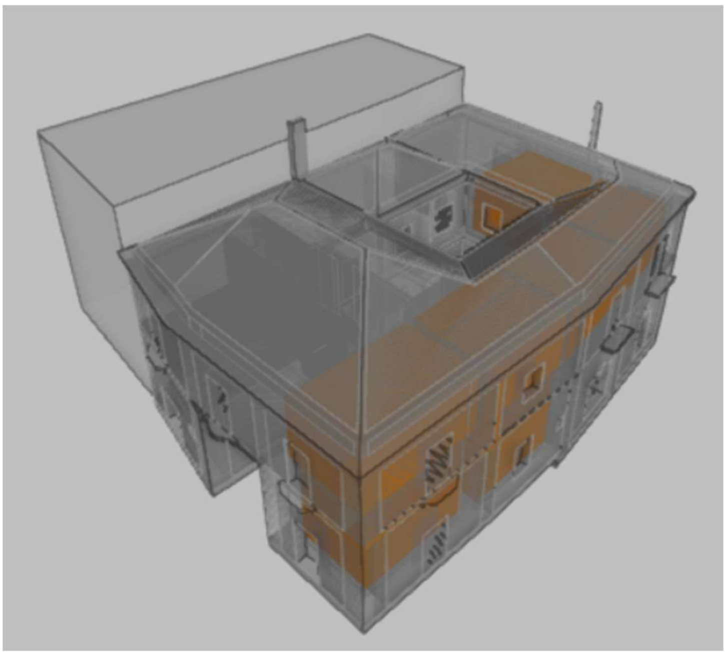


Figure 11: 3D graphical representation of the Frigento BEM

2.3.1 Envelope components and materials

This paragraph summarises the construction systems implemented within the Frigento 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 4 summarises all the materials implemented within the BEM.

Table 4: Materials

Layers					
Material	e	ρ	λ	RT	Cp
Plaster	2.00	1400.00	0.690	0.03	1000.00
Eq. masonry	96.00	1950.00	0.384	2.50	840.00
Eq. masonry	76.00	1950.00	0.380	2.00	840.00
Eq. masonry	66.00	1950.00	0.400	1.65	840.00
Eq. masonry	101.00	1950.00	0.385	2.63	840.00
Eq. masonry	81.00	1950.00	0.381	2.13	840.00
Eq. masonry	61.00	1950.00	0.400	1.53	840.00
Eq. masonry	71.00	1950.00	0.379	1.88	840.00
Eq. masonry	56.00	1950.00	0.400	1.40	840.00
Eq. masonry	86.00	1950.00	0.382	2.25	840.00
Reinforced concrete	30.00	2400.00	2.300	0.13	1000.00
Eq. masonry	36.00	1950.00	0.400	0.90	840.00
Plaster	1.50	1400.00	0.690	0.02	1000.00
Brick	12.00	1000.00	0.240	0.50	840.00
Impermeabilisation	0.30	1100.00	0.230	0.01	900.00
Concrete	4.00	2400.00	2.300	0.02	1000.00
Eq. floor slab	20.70	1600.00	0.647	0.32	840.00
Plaster	2.00	1400.00	0.690	0.03	1000.00
Internal flooring	2.00	2300.00	1.000	0.02	800.00
Screed	6.00	2000.00	1.400	0.04	1000.00
Concrete	4.00	2400.00	2.300	0.02	1000.00
Eq. floor slab	16.00	1600.00	0.320	0.50	840.00
Internal floorng	2.00	2300.00	1.000	0.02	800.00
Screed	5.00	2000.00	1.400	0.04	1000.00
Reinforced concrete	10.00	2400.00	2.300	0.04	1000.00
Gravel (areated)	25.00	1500.00	0.400	0.63	840.00

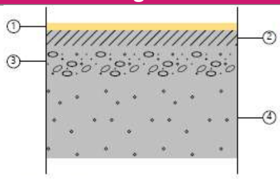
Used abbreviations			
e	*Thickness cm*	RT	*Thermal resistance (m²·K)/W*
ρ	*Density kg/m³*	Cp	*Specific heat J/(kg·K)*
λ	*Thermal conductivity W/(m·K)*		

Within Table 5 all the construction systems created for the Frigento 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 5: Construction systems

1.1 Floors in contact with the gorund

GF01

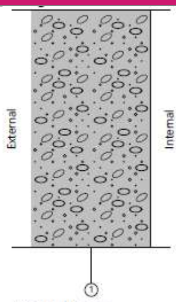
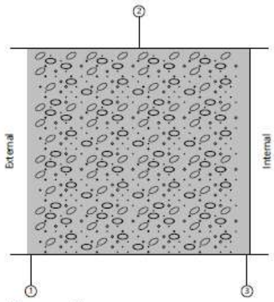
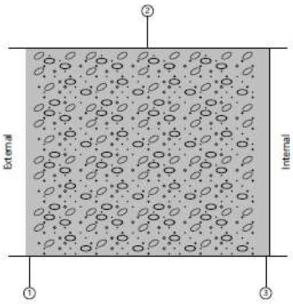
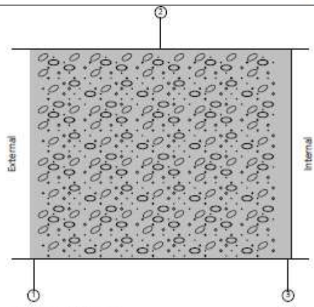


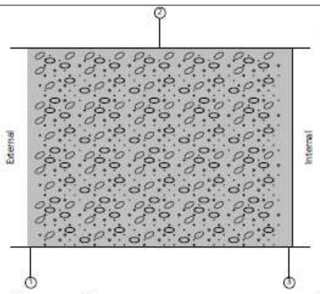
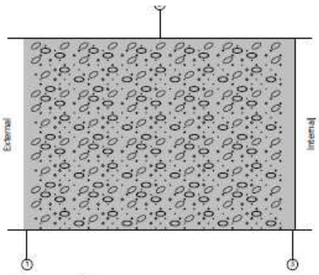
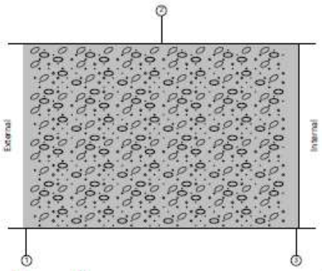
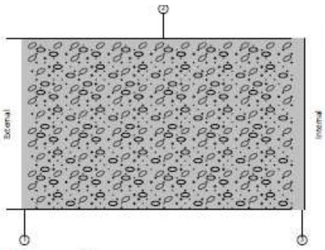
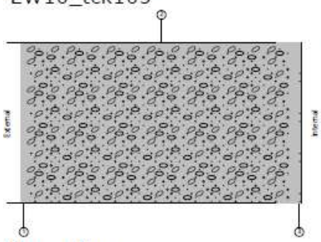
Layer list:

1 -	Internal floorng	2.00 cm
2 -	Screed	5.00 cm
3 -	Reinforced concrete	10.00 cm
4 -	Gravel (areated)	25.00 cm

Properties

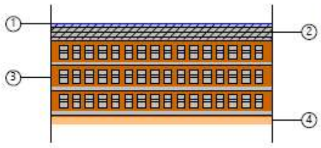
Thermal transmittance, U: 0.58 W/(m²·K)
Total thickness 42.00 cm
Characteristic length of, B': 2.028 m
Thermal resistance of the floor slab, Rf: 0.72 (m²·K)/W
Floor slab surface area, A: 16.69 m²
Floor slab perimeter, P: 16.456 m
Thermal conductivity, λ: 2.000 W/(m·K)

1.2 Façades	
Edge beam_tck 30	 Layer list: 1 - Reinforced concrete 30.00 cm Properties Thermal transmittance, U: 3.33 W/(m²·K) Total thickness 30.00 cm
EW03_tck65	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 61.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.57 W/(m²·K) Total thickness 65.00 cm
EW04_tck70	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 66.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.53 W/(m²·K) Total thickness 70.00 cm
EW05_tck75	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 71.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.48 W/(m²·K) Total thickness 75.00 cm

EW06_tck80	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 76.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.45 W/(m²·K) Total thickness 80.00 cm
EW07_tck85	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 81.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.42 W/(m²·K) Total thickness 85.00 cm
EW08_tck90	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 86.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.40 W/(m²·K) Total thickness 90.00 cm
EW09_tck100	 Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 96.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.37 W/(m²·K) Total thickness 100.00 cm
EW100_tck105	EW10_tck105  Layer list: 1 - Plaster 2.00 cm 2 - Eq. masonry 101.00 cm 3 - Plaster 2.00 cm Properties Thermal transmittance, U: 0.35 W/(m²·K) Total thickness 105.00 cm

1.3 Roofs

Sloped roof



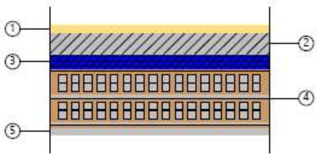
Layer list:

1 -	Impermeabilisation	0.30 cm
2 -	Concrete	4.00 cm
3 -	Eq. floor slab	20.70 cm
4 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 1.93 W/(m²·K)
Total thickness 27.00 cm

1.4 External floor

EF01



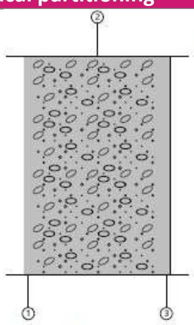
Layer list:

1 -	Internal flooring	2.00 cm
2 -	Screed	6.00 cm
3 -	Concrete	4.00 cm
4 -	Eq. floor slab	16.00 cm
5 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 1.24 W/(m²·K)
Total thickness 30.00 cm

2.1 Internal vertical partitioning

IW01_tck15

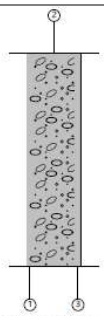


Layer list:

1 -	Plaster	2.00 cm
2 -	Eq. masonry	36.00 cm
3 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 0.82 W/(m²·K)
Total thickness 40.00 cm

IW02_tck40



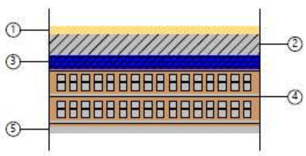
Layer list:

1 -	Plaster	1.50 cm
2 -	Brick	12.00 cm
3 -	Plaster	1.50 cm

Properties: Thermal transmittance, U: 1.24 W/(m²·K)
Total thickness 15.00 cm

2.2 Internal horizontal partitioning

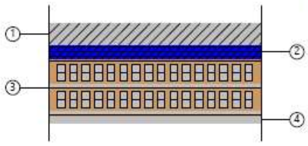
IF01



Layer list:

1 -	Internal flooring	2.00 cm
2 -	Screed	6.00 cm
3 -	Concrete	4.00 cm
4 -	Eq. floor slab	16.00 cm
5 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 1.24 W/(m²·K)
Total thickness 30.00 cm

IF02	 Layer list: 1 - Screed 6.00 cm 2 - Concrete 4.00 cm 3 - Eq. floor slab 16.00 cm 4 - Plaster 2.00 cm Properties: Thermal transmittance, U: 1.27 W/(m²·K) Total thickness 28.00 cm

The following table 6 summarises all the façade openings and windows.

Table 6: Construction systems

3.1 Façade openings	
ID02_100x210_w	Thermal transmittance, U: 2.39 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
ED01_130x240_w	Thermal transmittance, U: 2.38 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
ED02_200x210_w	Thermal transmittance, U: 2.38 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
ED04_110x210_w	Thermal transmittance, U: 2.35 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
ED05_100x210_w	Thermal transmittance, U: 2.35 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
Metal door_220x220_m	Thermal transmittance, U: 5.80 W/(m²·K) Absorptance, α_s: 0.800 (colour intermediate)
3.2 Windows	
W01_110x180_mf 2g	Thermal transmittance, U: 3.02 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.350
W02_150x140_mf 2g	Thermal transmittance, U: 3.06 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.300
W03_110x140_mf 2g	Thermal transmittance, U: 3.00 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.370
W04_40x60_mf 2g	Thermal transmittance, U: 3.11 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.240
W05_60x40_mf 2g	Thermal transmittance, U: 3.11 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.240
W06_50x50_mf 2g	Thermal transmittance, U: 3.12 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.230
W07_80x70_mf 2g	Thermal transmittance, U: 3.18 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.150
W08_50x70_mf 2g	Thermal transmittance, U: 3.12 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.220
W09_120x220_w 2g	Thermal transmittance, U: 3.05 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.310
W10_130x240_w 2g	Thermal transmittance, U: 2.74 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.430
W11_130x270_w 2g	Thermal transmittance, U: 2.73 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.440

W13_50x70_mf 2g	Thermal transmittance, U: 3.14 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.200
W14_100x260_w 2g	Thermal transmittance, U: 2.69 W/(m²·K) Solar factor, g: 0.700 Opaque fraction, Ff: 0.470

2.3.2 HVAC systems

Regarding the HVAC systems, the building is characterised by 2 separated heating systems. Each apartment is equipped by a condensing boiler for the heating and the domestic hot water production. Following images show the boiler and a typical radiator installed in one of the two flats.

with 2 single condensing boilers for both heating and domestic hot water production and radiators as terminals. No cooling systems or mechanical ventilation systems are installed.


Following table 7 summarises the main parameters of both HVAC systems.

Table 7: Construction systems

HVAC Systems	Flat Testa	Flat Cipriano
Reference name	Condensing Boiler_Testa	Condensing Boiler_Cipriano
Year of installation	n.a.	n.a.
Location of the generator	Internal heated space	Internal heated space
Rated capacity [kW]	32	24
Rated efficiency	95%	95%
Energy fuel	Natural gas	Natural gas
Supply/return [°C]	80/60	80/60
Terminal units	Radiators	Radiators

2.3.3 Occupancy, lighting, equipment and operating patterns

Frigento BEM has been characterised also under the point of view of the internal gains as summarised in following table 8.

Table 8: Internal gains features

OCCUPIED Space	Ventilation rates	LIGHTING Installed power	EQUIPMENT Installed power	PEOPLE	ACTIVITY level
Flat_Testa	0,5 ACH	5,5 W/mq	5,4 W/mq	25 mq/person	115 W/person
Flat_Cipriano	0,5 ACH	-	5,4 W/mq	25 mq/person	115 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 Frigento BEM.

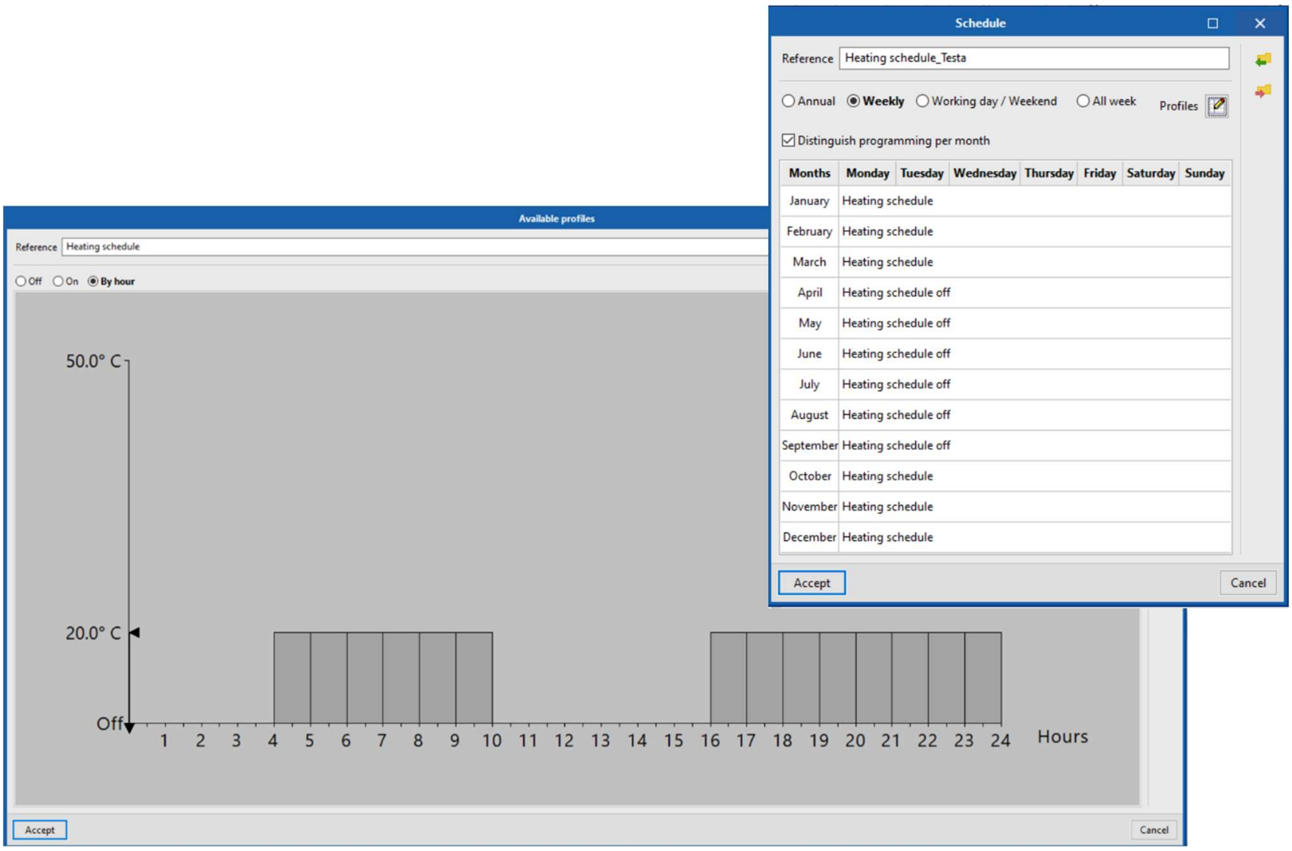


Figure 12: Heating schedule

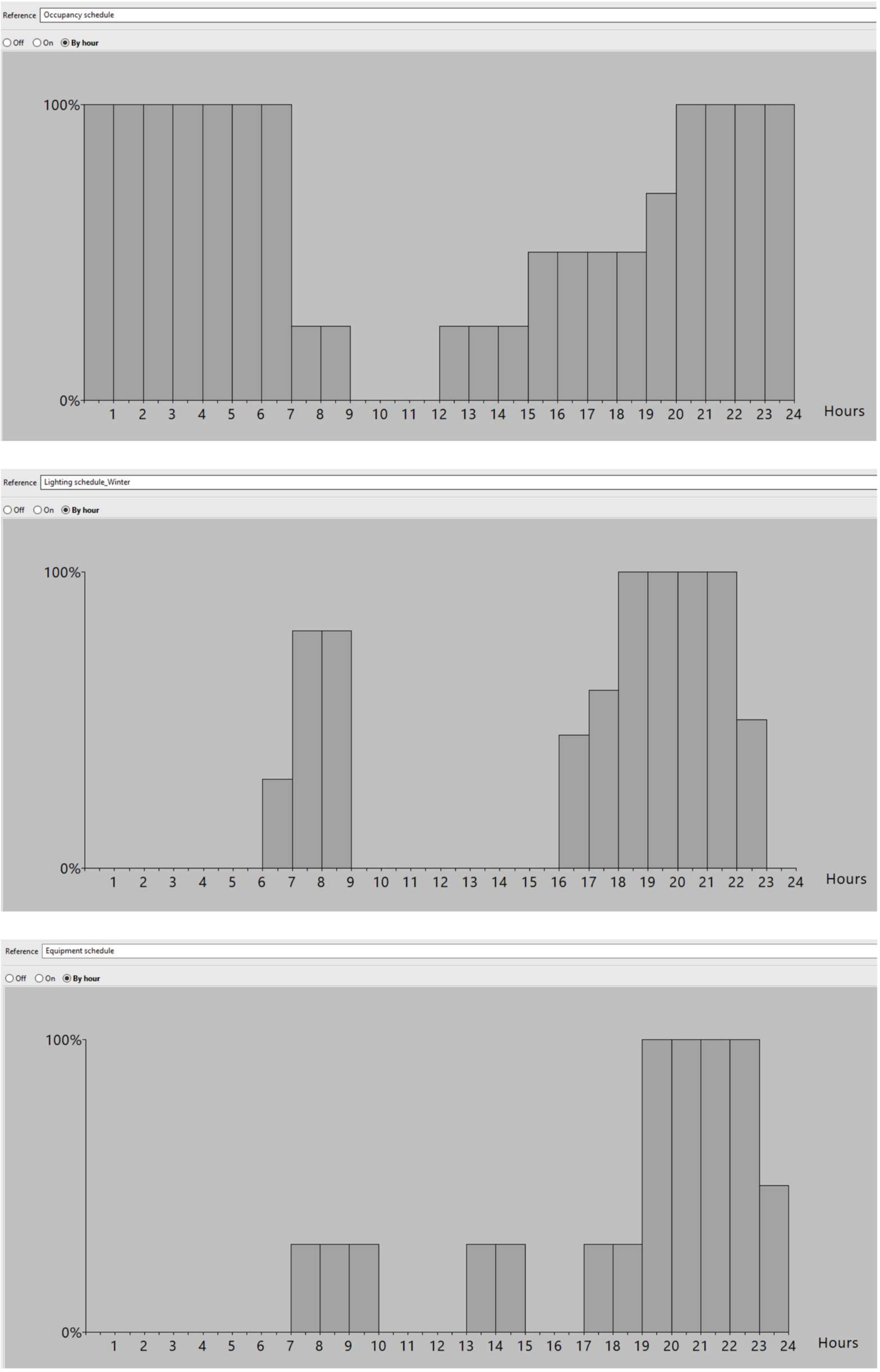


Figure 13: Occupancy, lighting and equipment schedule

3. BEM calibration

3.1 Validation methodology applied and results

This paragraph summarises the validation methodology applied to the Frigento BEM in order to check the reliability of the model and the related energy results. As the energy bills are not available, as well as the measurements of the indoor parameters, it was not possible to apply the full calibration methodology developed in Task 3.4.

A simplified validation has been performed comparing the average annual gas consumption calculated with the BEM model and the average annual consumption evaluated considering an average energy cost of 1 €/stm^3 and an annual energy cost of 2000 € for Testa flat and 1400€ for Cipriano Flat (general estimations provided by owners). The following table summarises the results of the simplified validation. The percentage difference between real and modelled consumption are less than 3%. This is acceptable and the BEM can be considered reliable. It can be used to evaluate the energy performance of the renovation scenarios as defined in the following paragraph.

Table 9: BEM validation results

BEM validation results		
Annual cost for heating (assumed)*	€	3400
Energy cost	€/stm^3	1.00
Average annual consumption_REAL (from assumptions)	**stm^3**	**3400**
Lower calorific value [kWh/stmc]	kWh/stm^3	9.27
Total consumption_BEM baseline	kWh	30628
Average annual consumption_BEM	**stm^3**	**3103**
Percentage difference	**%**	**2.82**

*2000 €/year for Flat Testa and 1400 €/year for Flat Cipriani (source building owner estimation)

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 0.35 – 1.93 W/mqK, and windows characterised by thermal transmittance varying between 2.69 – 3.18 W/mqK.

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 total energy consumption at consumption point and multiplied by the conversion factor (specific for Italy) for final energy to primary energy.

Table 10: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	102.61

Energy vector	$C_{ef,total}$ (kWh/year)	$C_{ef,total}$ (kWh/m²·year)	f_{cep}	$C_{ep,nr}$ (kWh/year)	$C_{ep,nr}$ (kWh/m²·year)
Natural gas	29202.95	97.83	1.049	30632.43	102.61

where:

$C_{ef,total}$: *Total energy consumption at consumption point, kWh/m²·year.*

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

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

BS.TED: Total Energy Demand

The table below summarises the results obtained from the calculation of the heating energy demand (there is no cooling for the Frigento demo) of each occupied zone, as well as the total energy demand of the building.

Table 11: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
Q_{FLAT_TESTA} [kWh/m²year]	100.37
$Q_{FLAT\_CIPRIANO}$ [kWh/m²year]	76.98
$Q_{TOTAL\ BUILDING}$ [kWh/m²year]	**86.15**

The following table shows the results of the total heat transferred by transmission and ventilation, the total internal heat, and the energy required for heating and cooling for each calculation zone of the building.

Table 12: Energy balance in each thermal zone

Flat_Testa (A_r = 181.41 m²; V = 614.41 m³)

	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)
Q_{op}	179.9	124.6	122.2	85.8	39.6	55.5	96.2	94.1	77.8	69.8	80.2	153.1	-17238.49	-95.02
	-2681.8	-2489.9	-2423.7	-772.8	-988.5	-953.6	-846.5	-896.0	-760.9	-1306.5	-1752.6	-2544.3		
Q_w	168.9	241.2	389.6	561.2	658.5	663.6	700.0	705.1	584.6	439.6	266.6	149.1	3034.95	16.73
	-392.6	-318.0	-288.8	-136.2	-98.1	-94.7	-117.7	-114.7	-120.3	-199.7	-249.9	-362.4		
Q_{ve+inf}	--	--	0.0	13.0	27.1	24.1	21.0	31.7	15.7	2.9	0.2	--	-7217.55	-39.79
	-1146.2	-996.5	-928.2	-423.1	-303.5	-290.1	-342.4	-310.8	-312.3	-555.4	-719.4	-1025.1		
Q_{equip}	200.4	181.0	200.4	194.0	200.4	194.0	200.4	200.4	194.0	200.4	194.0	200.4	2359.92	13.01
Q_{light}	230.4	208.1	230.4	197.6	204.1	197.6	120.6	120.6	116.7	219.6	212.5	219.6	2278.00	12.56
Q_{ocup}	305.9	276.2	302.8	330.1	318.7	258.6	219.9	222.1	253.1	292.0	289.5	304.9	3373.77	18.60
Q_H	**3174.8**	**2810.8**	**2437.6**	--	--	--	--	--	--	**881.4**	**1716.3**	**2943.5**	**13964.60**	**76.98**
Q_C	--	--	--	--	--	--	--	--	--	--	--	--	**0.00**	**0.00**
Q_{HC}	**3174.8**	**2810.8**	**2437.6**	--	--	--	--	--	--	**881.4**	**1716.3**	**2943.5**	**13964.60**	**76.98**

Flat_Cipriano (A_r = 117.11 m²; V = 377.01 m³)

	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)
Q_{op}	149.7	107.7	107.9	84.3	39.2	54.7	96.5	95.2	87.3	75.2	78.0	130.8	-14249.76	-121.68
	-2273.2	-2153.2	-2097.2	-629.5	-779.6	-735.9	-648.7	-706.8	-623.7	-1065.2	-1476.0	-2167.3		
Q_w	188.3	255.5	373.7	508.7	568.3	558.5	581.5	611.7	544.7	445.8	288.9	168.8	2683.94	22.92
	-379.8	-307.2	-280.2	-127.8	-88.4	-88.9	-116.7	-114.0	-121.1	-194.4	-241.8	-350.3		
Q_{ve+inf}	--	--	0.0	10.7	23.2	18.7	14.3	20.7	9.2	1.7	0.1	--	-4930.00	-42.10
	-786.0	-682.5	-635.4	-279.1	-191.2	-190.0	-238.9	-219.0	-224.4	-385.0	-494.8	-702.3		
Q_{equip}	129.4	116.9	129.4	125.2	129.4	125.2	129.4	129.4	125.2	129.4	125.2	129.4	1523.40	13.01
Q_{light}	148.8	134.4	148.8	127.5	131.8	127.5	77.9	77.9	75.4	141.8	137.2	141.8	1470.52	12.56
Q_{ocup}	197.6	178.4	195.6	214.8	208.9	169.2	141.5	142.3	161.6	188.0	186.8	196.9	2181.71	18.63
Q_H	**2661.9**	**2384.3**	**2094.6**	--	--	--	--	--	--	**697.3**	**1428.3**	**2487.4**	**11753.67**	**100.37**
Q_C	--	--	--	--	--	--	--	--	--	--	--	--	**0.00**	**0.00**
Q_{HC}	**2661.9**	**2384.3**	**2094.6**	--	--	--	--	--	--	**697.3**	**1428.3**	**2487.4**	**11753.67**	**100.37**

A_f:	*Net surface area of the thermal zone, m².*
V:	*Internal net volume of the thermal zone, m³.*
Q_{op}:	*Energy transfer corresponding to the thermal transmission across opaque elements of the envelope, kWh/m²·year.*
Q_w:	*Energy transfer corresponding to the thermal transmission across light elements of the envelope, kWh/m²·year.*
Q_{ve+inf}:	*Energy transfer corresponding to the thermal transmission due to ventilation, kWh/m²·year.*
Q_{equip}:	*Energy transfer corresponding to the internal heat gain due to internal equipment, kWh/m²·year.*
Q_{light}:	*Energy transfer corresponding to the internal heat gain due to lighting, kWh/m²·year.*
Q_{ocup}:	*Energy transfer corresponding to the internal heat gain due to internal occupancy, kWh/m²·year.*
Q_H:	*Heating energy input, kWh/m²·year.*
Q_C:	*Cooling energy input, kWh/m²·year.*
Q_{HC}:	*Heating and cooling energy input, kWh/m²·year.*

The following figure shows the energy balance of the building for each month, taking into account the energy lost or gained due to thermal transmission via opaque and light elements (Q_{op} and Q_w, respectively), the energy interchange due to ventilation and infiltrations (Q_{ve+inf}), the gain in heat due to occupancy (Q_{ocup}), lighting (Q_{light}) and internal equipment (Q_{equip}) as well as the necessary heating (Q_H) and cooling (Q_C) inputs.

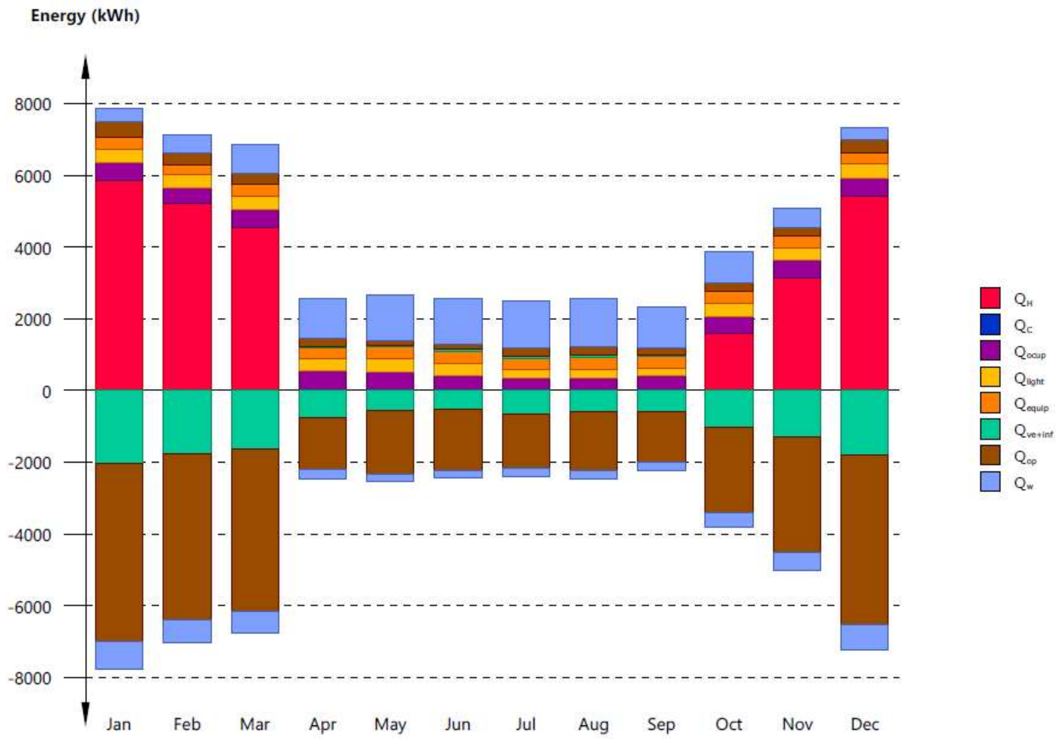


Figure 14: Energy balance chart of the building

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 13: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	100.8
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	Not relevant for the demo
EP_{dhw}[kWh/m²]	16.1
EP_{TOT}[kWh/m²]	**102.6**

		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 = 298.52 m²; V = 991.42 m³)															
Energy demand	Heating	5836.7	5195.1	4532.2	--	--	--	--	--	--	1578.7	3144.7	5430.9	25718.3	86.2
	DHW	370.4	334.5	370.4	358.4	370.4	358.4	370.4	370.4	358.4	370.4	358.4	370.4	4360.9	14.6
	TOTAL	6207.1	5529.6	4902.6	358.4	370.4	358.4	370.4	370.4	358.4	1949.1	3503.1	5801.3	30079.2	100.8
Natural gas (f_{cep} = 1.049)	EF_{heat}	5612.8	4996.7	4334.8	--	--	--	--	--	--	1470.9	2979.0	5218.2	24612.5	82.4
	EP_{heat}	5893.5	5246.6	4551.5	--	--	--	--	--	--	1544.5	3128.0	5479.1	25843.1	86.6
	$EP_{nr,heat}$	5887.6	5241.3	4547.0	--	--	--	--	--	--	1542.9	3124.8	5473.7	25817.3	86.5
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	389.9	352.1	389.9	377.3	389.9	377.3	389.9	389.9	377.3	389.9	377.3	389.9	4590.4	15.4
	EP_{dhw}	409.4	369.8	409.4	396.2	409.4	396.2	409.4	409.4	396.2	409.4	396.2	409.4	4820.0	16.1
	$EP_{nr,dhw}$	409.0	369.4	409.0	395.8	409.0	395.8	409.0	409.0	395.8	409.0	395.8	409.0	4815.1	16.1
Auto-consumed electricity (f_{cep} = 1.950)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	6002.7	5348.9	4724.6	377.3	389.9	377.3	389.9	389.9	377.3	1860.8	3356.3	5608.1	29202.9	97.8
	C_{ep}	6302.8	5616.3	4960.9	396.2	409.4	396.2	409.4	409.4	396.2	1953.8	3524.1	5888.5	30663.1	102.7
	$C_{ep,nr}$	6296.5	5610.7	4955.9	395.8	409.0	395.8	409.0	409.0	395.8	1951.9	3520.6	5882.6	30632.4	102.6

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.
$C_{ef,total}$: Total energy consumption at consumption point, kWh/m²·year.
C_{ep}: Total primary energy consumption, kWh/m²·year.
$C_{ep,nr}$: Total non-renewable primary energy consumption, kWh/m²·year.

5. Building renovation scenarios

To perform and assess multiple energy simulations for building renovation scenarios, the MTB Optimisation tool has been applied.

5.1 Renovation scenarios proposed

For the Frigento democase, the following building renovation elements have been assessed according to Task 7.1 premises.

- External walls (indoor) insulation
- Windows replacement (incl. shading system)
- Indoor floors insulation
- Boilers replacement

5.2 Optimisation set-up: planning variants considered

The following table summarizes the optimization setting applied to the Frigento BEM model. For each type of intervention, different solutions were examined, making the characteristic parameters vary between a certain range of values.

Table 14: Optimisation setting – Intervention, ranges of variation and number of options

Type of intervention	Optimisation settings and ranges of variation	Number of options
External walls insulation	Insulation Types: (1) Stone wool (λ 0,035 W/mK); (2) Mineral wool (λ 0,032 W/mK); (3) Wood derivates wood wool (λ from 0,038 W/mK)	3
	Thickness options: 1 cm – 30 cm in 10 regular steps (1, 4, 7, 11, 14, 17, 20, 23, 27, 30 cm)	10
Roof insulation	Insulation Types: (1) Stone wool (λ 0,035 W/mK); (2) Mineral wool (λ 0,032 W/mK); (3) PUR foam (λ 0,026 W/mK)	3
	Thickness options: 1 cm – 32 cm in 10 regular steps (1, 4, 7, 11, 14, 18, 21, 25, 29, 32 cm)	10
Ground floor insulation	Insulation Types: (1) EPS (λ 0,034 W/mK); (2) XPS (λ 0,035 W/mK); (3) PUR foam (λ 0,032 W/mK)	3
	Thickness options: 1 cm – 30 cm in 10 regular steps (1, 4, 7, 11, 14, 17, 20, 23, 27, 30 cm)	10
Windows replacement	U-values from 1,3 to 0,7 kWh/m²K (steps: 1,3; 1,1; 1,0; 0,9; 0,7) no change in windows dimensions	5
Shading system	(1) Interior blind with low reflectivity slats; (2) Exterior shade roll medium translucent; (3) Exterior blinds w. low/med/high reflectivity and 30°-135° angle	19
Photovoltaic	No PV	1
HVAC	Heat distribution: (1) Hot water radiator; (2) Fan coil unit Heat supply: (1) Condensation boiler; (2) Gas Boiler & Air source heat pump	2 2
	Total number of theoretical combinations	**10.260.000**

5.3 Ranges of optimal solutions

Following the specific optimization set-up of the project, the theoretical number of possible renovation scenarios to be assessed is 10,26 Million. Out of these, 4.000 scenarios have been automatically simulated and assessed, controlled by an evolutionary optimization algorithm. This process took a computation time of approx. 11hrs (10hrs 48min on a server cluster with 288 cores and 470 GB RAM involving server costs of approx. 65€).

Figure 15 shows the Pareto-graph of simulates renovation scenarios, sorted by construction costs and energy demand. The solution space includes renovation scenarios with resulting end energy demands between 51 – 72 kWh/(m² year) and construction costs between EUR 250.000 and EUR 350.000.The points within the red circle represent a range of optimal solutions reducing both energy demand and construction costs.

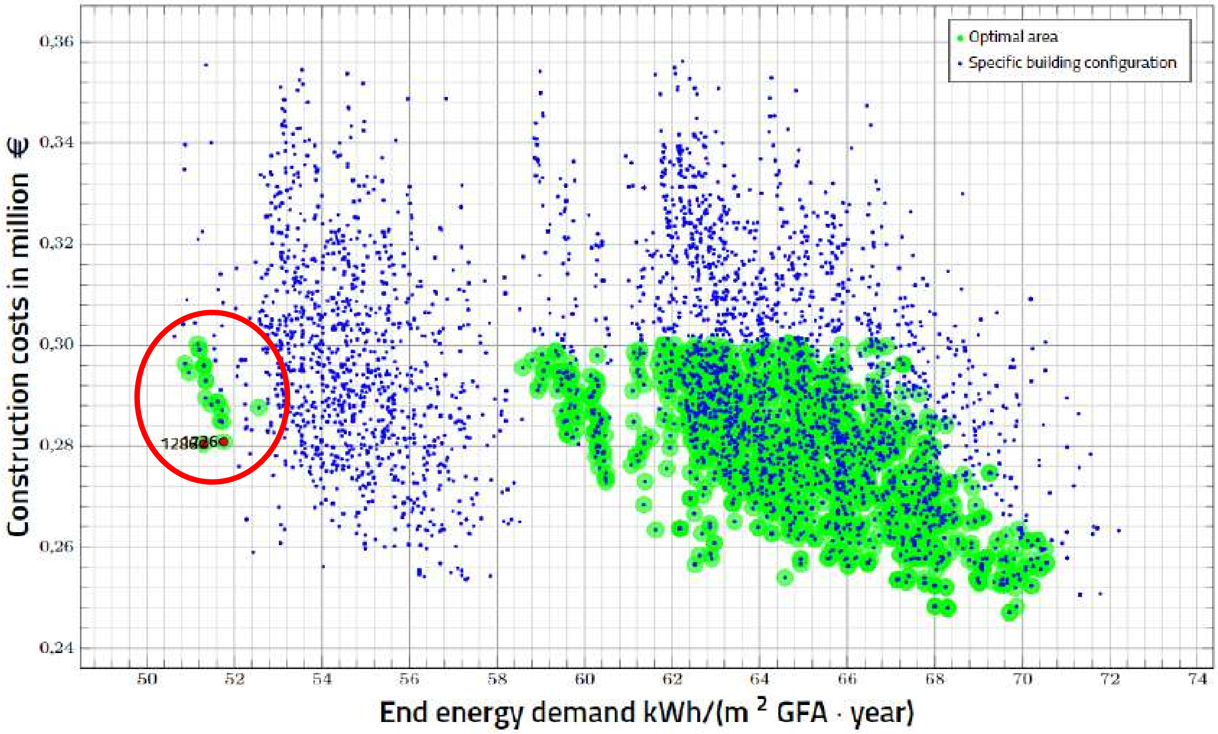


Figure 15: Pareto-graph of simulates renovation scenarios

Out of this solution space, four renovation scenarios have been identified as among optimal solutions:

- Energy-optimal: Two solutions with best results in end energy demand, while still having a good costs and comfort performance (ID 1286 & ID 1726)
- Cost-optimal: Two solutions with best results in cost performance, while still having a good energy and comfort performance (ID 2224 & ID 2547)

Those two Energy-optimal renovation alternatives are being described in the following.

5.4 Scenarios 1: description and results

Scenario 1 (ID 1286) has been identified as an energy-optimal renovation scenario. In comparison with all simulated renovation scenarios, this scenario has a very good end energy demand, while still having a good costs and comfort performance (17). Its configuration and its simulation results are described in the following tables.

Table 15: Renovation setup for the energy-optimal scenario 1 (ID 1286)

Type of intervention	Optimisation settings and ranges of variation	
External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,24 m 0,46 m 0,14 W/m²K
Roof insulation	Insulation material: Mineral wool Total thickness U-Value	0,23 m 0,60 m 0,14 W/m²K

Ground floor insulation	Insulation material: XPS Total thickness U-Value	0,10 m 0,21 m 3,75 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind high reflectivity slats 60°	
HVAC	Heat distribution: Hot water radiator Heat supply: Air-source heatpump & Gas boiler support Cooling: None	

Sustainability insights

	AI-generated solution (ID 1286)
Primary energy consumption	89.48 kWh/(m² · a)
Energy demand for cooling	0.00 kWh/(m² · a)
Energy demand for domestic hot water	12.14 kWh/(m² · a)
Electricity demand	38.88 kWh/(m² · a)
Energy demand for heating	13.97 kWh/(m² · a)
Energy demand total	51.30 kWh/(m² · a)
PV electricity production	0.00 kWh/(m² · a)

Figure 16: Screenshot from the optimisation report with energy related KPIs

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 16: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	89,48

BS.TED: Total Energy Demand

Table 17: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
Q_{TOT} [kWh/m²year]	51,30

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

Table 18: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	13,97
EP_{cool}[kWh/m²]	0.00 (Cooling not present)
EP_{light}[kWh/m²]	Not relevant for the demo
EP_{dhw}[kWh/m²]	12,14
EP_{TOT}[kWh/m²]	**51,30**

BS.TES: Total Energy savings

Table 19: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 02	SAVING
EP_{heat}[kWh/m^2]	100,8	13,97	86,83
EP_{cool}[kWh/m^2]	Cooling not present		
EP_{light}[kWh/m^2]	Not relevant for the demo		
EP_{dhw}[kWh/m^2]	16,1	12,14	3,96
EP_{TOT}[kWh/m^2]	**102,6**	**51,30**	**51,3**

5.5 Scenarios 2: description and results

Scenario 2 (ID 1726) has been identified as an energy-optimal renovation scenario. In comparison with all simulated renovation scenarios, this scenario has a very good end energy demand, while still having a good costs and comfort performance (**Error! Reference source not found.**). Its configuration and its simulation results are described in the following tables.

Table 20: Renovation setup for the energy-optimal scenario 1 (ID 1286)

Type of intervention	Optimisation settings and ranges of variation	
External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,21 m 0,43 m 0,16 W/m²K
Roof insulation	Insulation material: Stone wool Total thickness U-Value	0,23 m 0,60 m 0,14 W/m²K
Ground floor insulation	Insulation material: EPS Total thickness U-Value	0,18 m 0,49 m 3,75 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind high reflectivity slats 60°	
HVAC	Heat distribution: Hot water radiator Heat supply: Air-source heatpump & Gas boiler support Cooling: None	

Sustainability insights

	AI-generated solution (ID 1726)
Primary energy consumption	90.35 kWh/(m^2 · a)
Energy demand for cooling	0.00 kWh/(m^2 · a)
Energy demand for domestic hot water	12.15 kWh/(m^2 · a)
Electricity demand	39.31 kWh/(m^2 · a)
Energy demand for heating	14.35 kWh/(m^2 · a)
Energy demand total	51.76 kWh/(m^2 · a)
PV electricity production	0.00 kWh/(m^2 · a)

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 21: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	90,35

BS.TED: Total Energy Demand

Table 22: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
Q_{TOT} [kWh/m^{2}year]	51,73

Figure 17: Details from optimisation report with energy related KPIs (Scenario 2)

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

Table 23: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m^2]	14,35
EP_{cool}[kWh/m^2]	0.00 (Cooling not present)
EP_{light}[kWh/m^2]	Not relevant for the demo
EP_{dhw}[kWh/m^2]	12,15
EP_{TOT}[kWh/m^2]	**51,76**

BS.TES: Total Energy savings

Table 24: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 02	SAVING
EP_{heat}[kWh/m^2]	100,8	14,35	86,45
EP_{cool}[kWh/m^2]	Cooling not present		
EP_{light}[kWh/m^2]	Not relevant for the demo		
EP_{dhw}[kWh/m^2]	16,1	12,15	3,95
EP_{TOT}[kWh/m^2]	**102,6**	**51,76**	**51,84**

6. Time reduction evaluation

Following table shows the results of the time reduction for the Frigento 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 25: 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	0,5
	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		0,5	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		2	creation of the Analytical model using BIM (just minor adjustments may be needed)	0,5
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	2
	TOTAL TIME REQUIRED		**16**		**9**
BIM-to-BEM time reduction compared to current practice: 44%					