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

Deliverable 4.2 – Energy Performance Report – Tempelhof 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 - TEMPELHOF

Deliverable 4.2 – Energy Performance Report

Issue Date	31st October 2022
Produced by	TUB (Saket S.)
Version:	V 01
Dissemination	Public

Colophon

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1. General information

1.1 Building description

Tempelhof demo case (H2rund) is a multi-story residential building, which was formerly the officers' hotel of the US Americans, located in Berlin (Germany), in the south-central Berlin borough of Tempelhof-Schöneberg, it ceased operating in 2008. The Tempelhof airport complex consists of several staggered structures: The plaza, originally planned as a circle, is surrounded by four-story wings, which were to house the administrations of Deutsche Lufthansa and the Berlin Airport Company, as well as sections of the Reich Aviation Ministry. The buildings surround a 90-meter-long front courtyard, which leads to the monumental lobby building. This structure in turn leads to the 18-meter-high, longitudinally oriented terminal building.

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

The building was formerly the officers' hotel of the US Americans. The first tenant was Deutsche Lufthansa, which was founded in 1926 in Tempelhof. Along with its subsidiary Hansa Luftbild, it moved in 1938 in the airport building designed by Ernst Sagebiel. H2rund forms a representative access to central headquarters with its large reception hall. The rooms used for military purposes in the Second World War were completely destroyed and burnt out by the end of the war. In 1950, Berliner Flughafen Gesellschaft began reconstruction for US Air Force, which built the Officers' Club and Officers' mess with dining room and club rooms under the name "Columbia House". Officers' quarters were built from former office rooms on upper floors. The reception area on the ground floor was completely redesigned in 1987. Even the projecting roof comes from the US American period. The staircases with characteristic aluminum rails and "oak hall" have largely been preserved in their original state. This room spanning over two floors got its name because of wood paneling and candlesticks adorned with oak leaves. Originally it served Lufthansa as a conference and lecture hall with inbuilt screen for movie screenings.

The building consists of 6 floors (4 floor with 2underground floors), 2 stairwells on each floor. The constructive characteristics of the building are consistent with the construction period and are characterized by brick walls with limestone shells, reinforced concrete and brick mixed floors, and a slope roof.

Regarding the HVAC systems, the building is characterized by central heating systems. The whole building is equipped with district heating for the heating and domestic hot water production. No cooling systems or mechanical ventilation systems are installed. The following photos show the external view of the building.

This project, sponsored by the European Union's Horizon 2020 research and innovation initiative, aims to provide a comprehensive approach to transforming European cities into sustainable, smart, and resource-efficient urban settings. The renovation efforts will include repurposing the airport building into an office building and defining different renovation scenarios for better energy performance which will be building envelope insulation, with a focus on the façades and roof, as well as internal horizontal partitioning.

Figure 2: Main façade of the building

Following a summary of the demo general data

Table 1: General information

General information	
Location	Berlin (Germany)
Use category	Residential
Building type	Multi-story building
Construction year	1926
Renovation year	2022
Number of floors	4 + 2 Underground
Number of apartments/units	

1.2 GIS and environmental data

Berlin (Tempelhof) climate data was downloaded directly from the climate.onebuilding.org website.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	0.5 °C (33) °F	1.4 °C (34.5) °F	4.4 °C (40) °F	9.7 °C (49.4) °F	14.4 °C (58) °F	17.8 °C (64) °F	19.8 °C (67.7) °F	19.5 °C (67.1) °F	15.5 °C (59.8) °F	10.4 °C (50.7) °F	5.6 °C (42.1) °F	2.2 °C (36) °F
Min. Temperature °C (°F)	-1.9 °C (28.6) °F	-1.4 °C (29.5) °F	0.6 °C (33.2) °F	4.6 °C (40.3) °F	9.4 °C (48.9) °F	12.9 °C (55.2) °F	15.2 °C (59.4) °F	14.9 °C (58.9) °F	11.4 °C (52.6) °F	7.3 °C (45.1) °F	3.2 °C (37.7) °F	0.1 °C (32.2) °F
Max. Temperature °C (°F)	2.8 °C (37) °F	4.4 °C (40) °F	8.4 °C (47.1) °F	14.4 °C (57.9) °F	18.9 °C (66.1) °F	22.1 °C (71.8) °F	24 °C (75.3) °F	23.9 °C (75) °F	19.6 °C (67.2) °F	13.8 °C (56.8) °F	8 °C (46.4) °F	4.2 °C (39.6) °F
Precipitation / Rainfall mm (in)	56 (2)	41 (1)	53 (2)	42 (1)	60 (2)	67 (2)	81 (3)	62 (2)	56 (2)	49 (1)	48 (1)	54 (2)
Humidity(%)	84%	81%	77%	68%	66%	64%	65%	65%	71%	80%	86%	84%
Rainy days (d)	9	7	9	8	8	8	9	8	7	7	8	9
avg. Sun hours (hours)	2.7	3.9	5.4	8.7	10.2	11.0	10.9	10.2	7.4	5.0	3.5	2.6

Figure 3: Berlin's Weather information

The following a brief summary of the climate data.

Table 2: General environmental data

General environmental data	
Location	Berlin (Germany)
Weather file	DEU_BE_Berlin-Tempelhof.AP.103840_TMYx
Altitude [m]	34
Latitude [degrees]	52°52'0'' N
Longitude [degrees]	13°40'5'' E

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

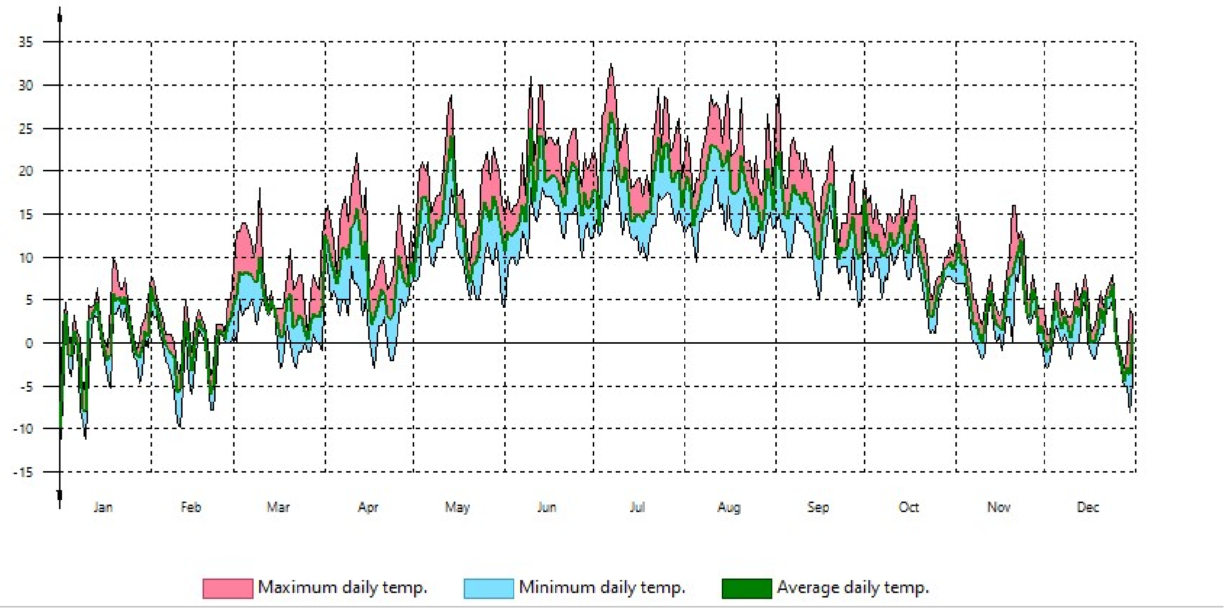


Figure 4: External temperature imported into the BEM model

2. Energy modelling

2.1 BIM-to-BEM procedure and software tools used

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

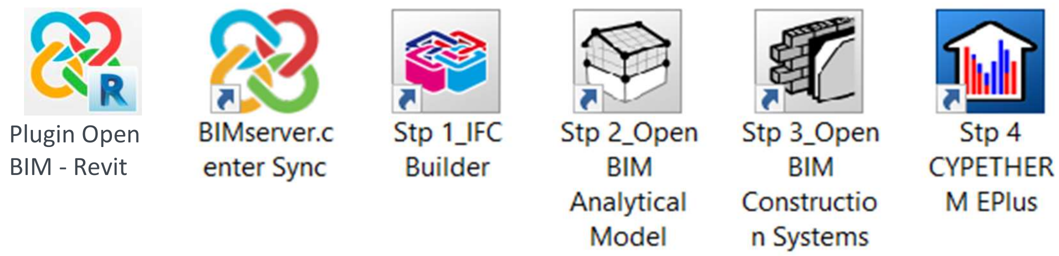


Figure 5: Software tools used to complete the BIM-to-BEM procedure

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

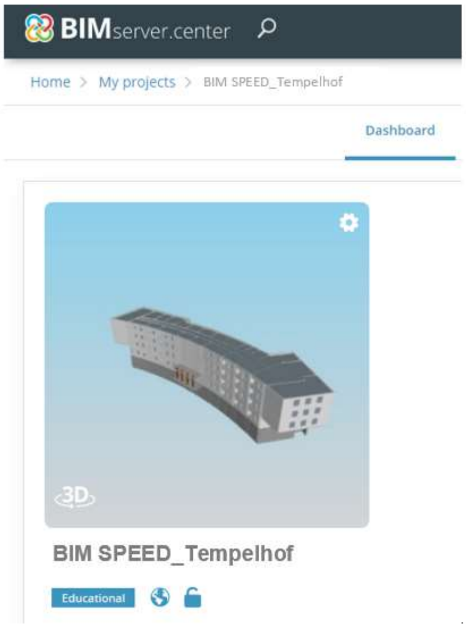


Figure 6: BIM SPEED_Tempelhof Project on the BIMserver.center platform

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

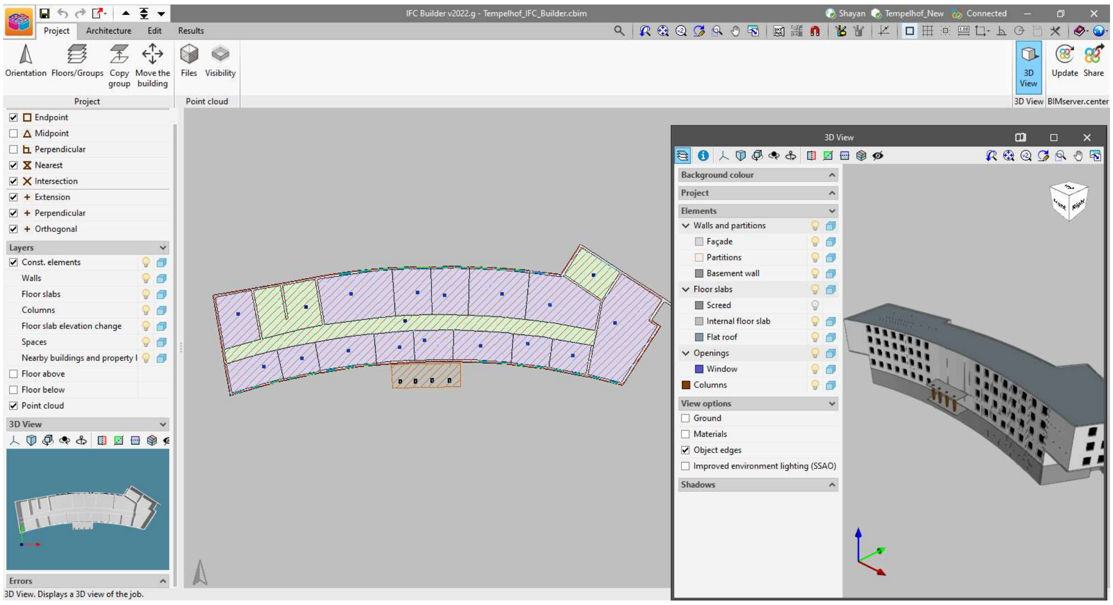


Figure 7: Tempelhof demo – IFC Builder

The model has then been exported and synchronized in BIMserver.center and opened 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 7 different thermal zones have been defined and associated with the relevant spaces defined previously with IFC Builder:

- Z01: Basement (not heated)
- Z02: Common Area (not heated)
- Z03 to Z07: Office floors (heated)

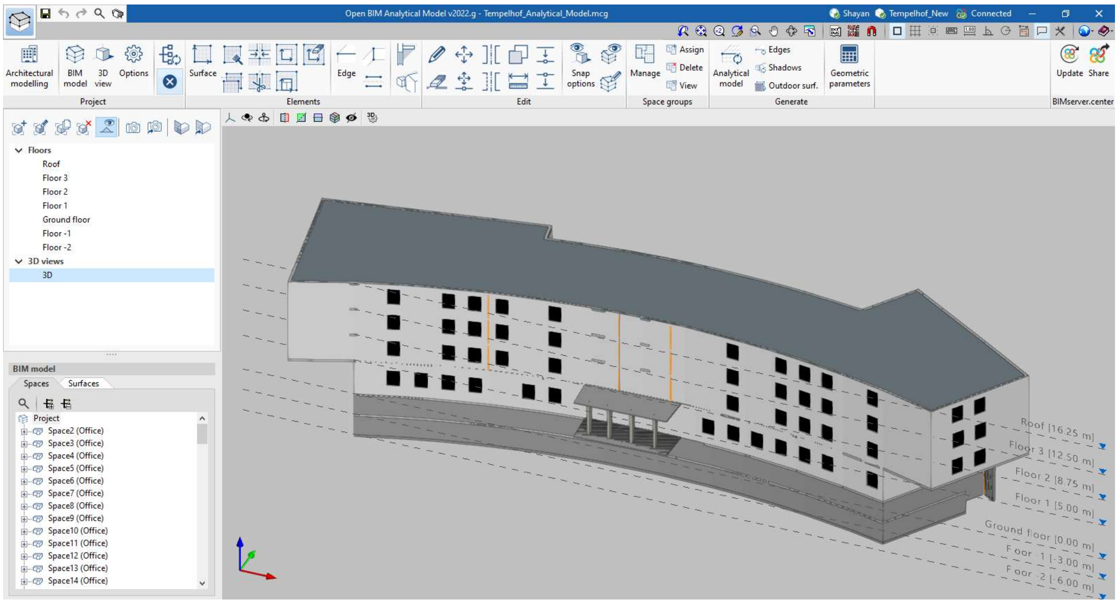


Figure 8: Tempelhof demo – Open BIM Analytical Model

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.

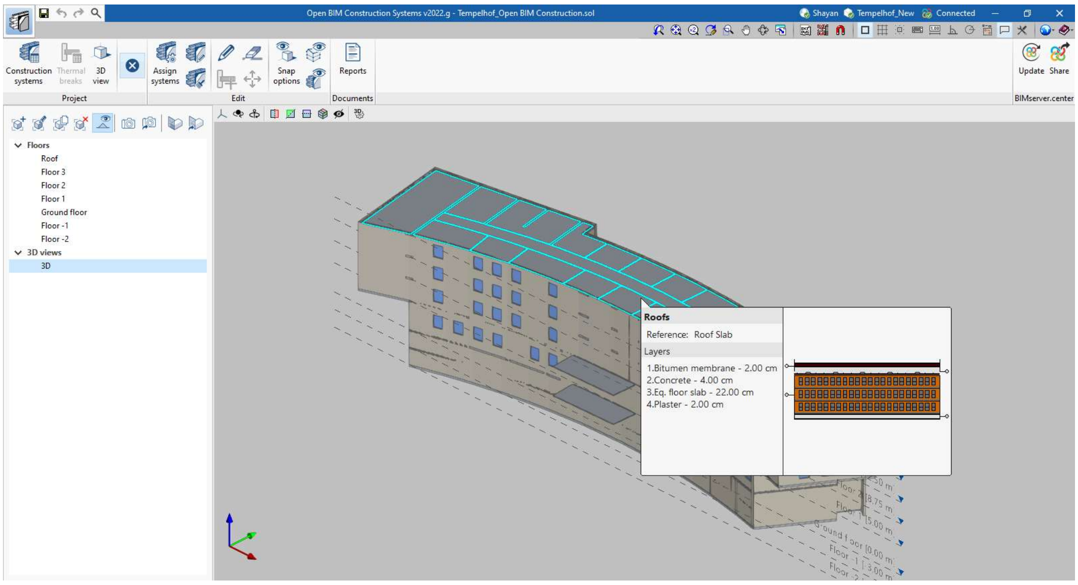


Figure 9: Tempelhof demo – Open BIM Construction Systems

As previously done, the model has been exported to the BIMserver.center ready to move to the 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 user profiles as described within 2.3 paragraph.

2.2 Description of BEM's technical features

Tempelhof BEM consists of 90 office spaces, 2 common not-heated stairwell, a not-heated corridor in each floor, and a flat roof. Figure 11 shows the layout of a typical floor while Figure 12 provides the 3D graphical representation of the Tempelhof BEM as completed in Cypetherm Eplus.

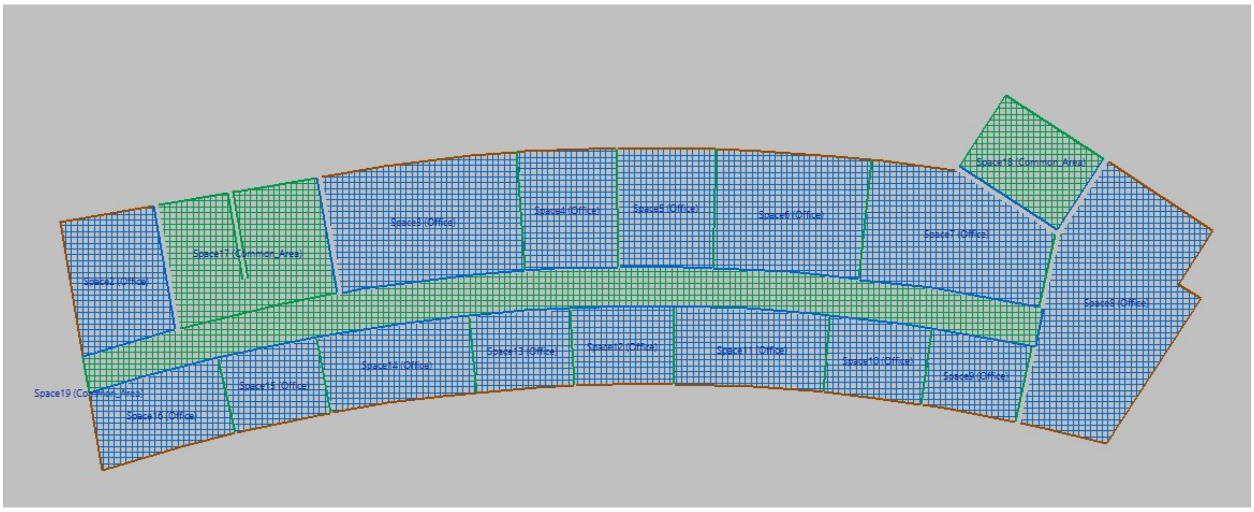


Figure 10: Typical floor layout Tempelhof BEM

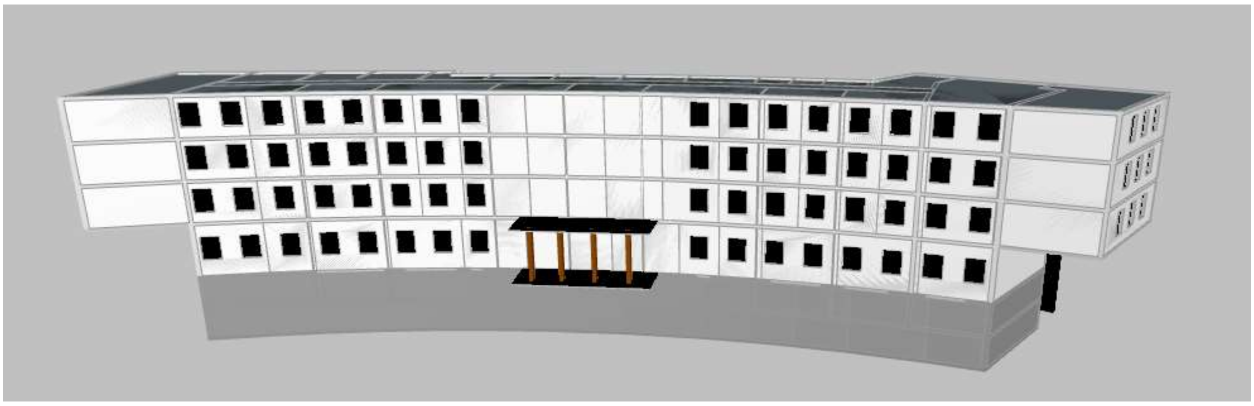


Figure 11: 3D graphical representation of the Tempelhof BEM

2.2.1 Envelope components and materials

This paragraph summarises the construction systems implemented within the Tempelhof BEM to characterize the thermal behavior 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.

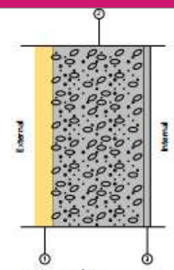
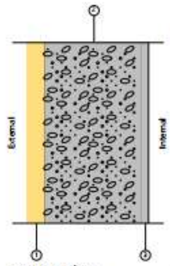
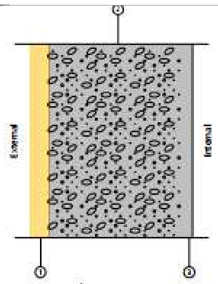
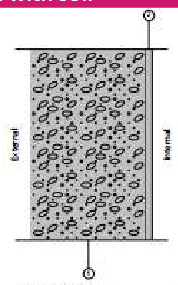
Table 3: Materials

Layers					
Material	e	ρ	λ	RT	Cp
Facadeshellimestone	6.00	2750.00	1.200	0.05	840.00
Eq. Brick wall	30.00	1920.00	0.500	0.60	840.00
Plaster	2.00	1400.00	0.667	0.03	1000.00
Eq.masonry	42.00	1920.00	0.500	0.84	840.00
Facadeshelllimestone	6.00	2750.00	1.200	0.05	840.00
Eq. Brick wall	32.00	1920.00	0.500	0.64	840.00
Plaster	2.00	1400.00	0.667	0.03	1000.00
Plaster	1.50	1400.00	0.750	0.02	1000.00
Brick	9.00	1000.00	0.200	0.45	840.00
Eq.masonry	35.00	1950.00	0.407	0.86	840.00
Eq.masonry	47.00	1950.00	0.392	1.20	840.00
Eq. Brick wall	38.00	1920.00	0.500	0.76	840.00
Eq. Brick wall	48.00	1920.00	0.500	0.96	840.00
Eq. Brick wall	36.00	1920.00	0.500	0.72	840.00
Internalflooring	2.00	2300.00	1.000	0.02	800.00
Screed	6.00	2000.00	1.500	0.04	1000.00
Concrete	4.00	2400.00	2.000	0.02	1000.00
Eq.floorslab	16.00	1600.00	0.320	0.50	840.00
Bitumenmembrane	2.00	1100.00	0.180	0.11	900.00
Eq.floorslab	22.00	1600.00	0.400	0.55	840.00
Eq.floorslab	16.00	1600.00	0.400	0.40	840.00
Screed	5.00	2000.00	1.250	0.04	1000.00
Reinforcedconcrete	10.00	2400.00	2.500	0.04	1000.00
Gravel	15.00	1500.00	0.395	0.38	840.00

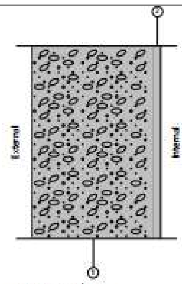
Used abbreviations			
e	*Thickness cm*	RT	*Thermal resistance (m²·K)/W*
ρ	*Density kg/m³*	Cp	*Specific heat J/(kg·K)*
λ	*Thermal conductivity W/(m·K)*		

Within Table 4 all the construction systems created for the Tempelhof 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	
Basic wall STB 380 (38.00 cm)	 Properties Layer list: 1 - Facade shel limestone 6.00 cm 2 - Eq. Brick wall 30.00 cm 3 - Plaster 2.00 cm Thermal transmittance, U: 1.18 W/(m²·K) Total thickness 38.00 cm
Basic wall STB 400 (40.00 cm)	 Properties Layer list: 1 - Facade shell limestone 6.00 cm 2 - Eq. Brick wall 32.00 cm 3 - Plaster 2.00 cm Thermal transmittance, U: 1.12 W/(m²·K) Total thickness 40.00 cm
Basic wall STB 500 (50.00 cm)	 Properties Layer list: 1 - Facade shel limestone 6.00 cm 2 - Eq. masonry 42.00 cm 3 - Plaster 2.00 cm Thermal transmittance, U: 0.92 W/(m²·K) Total thickness 50.00 cm
1.2 Walls in contact with soil	
BW STB 380	 Properties Layer list: 1 - Eq. Brick wall 36.00 cm 2 - Plaster 2.00 cm Thermal transmittance, U: 0.32 W/(m²·K) Total thickness 38.00 cm

BW STB 400

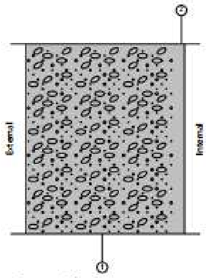


Layer list:

1 -	Eq. Brick wall	38.00 cm
2 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 0.32 W/(m²·K)
Total thickness 40.00 cm

BW STB 500



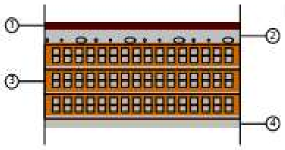
Layer list:

1 -	Eq. Brick wall	48.00 cm
2 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 0.29 W/(m²·K)
Total thickness 50.00 cm

2.1 Roof

Roof slab (30.00cm)



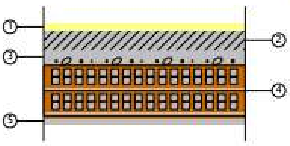
Layer list:

1 -	Bitumen membrane	2.00 cm
2 -	Concrete	4.00 cm
3 -	Eq. floor slab	22.00 cm
4 -	Plaster	2.00 cm

Properties: Thermal transmittance, U: 1.18 W/(m²·K)
Total thickness 30.00 cm

2.2 Internal horizontal partitioning

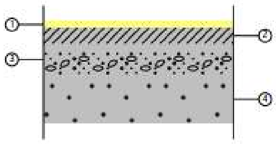
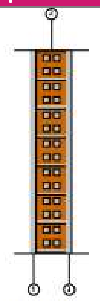
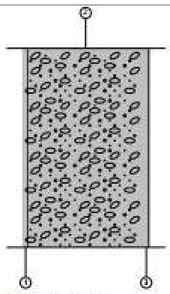
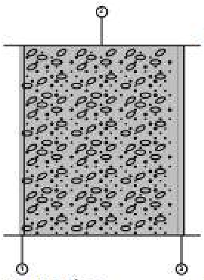
Hochlsteindecke 300 (30.00 cm)



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: 1.41 W/(m²·K)
Total thickness 30.00 cm

Screed Betondecke 320 (32.00 cm)	 Layer list: 1 - Internal flooring 2.00 cm 2 - Screed 5.00 cm 3 - Reinforced concrete 10.00 cm 4 - Gravel 15.00 cm Properties Thermal transmittance, U: 0.20 W/(m²·K) Total thickness 32.00 cm Characteristic length of, B': 13.490 m Thermal resistance of the floor slab, Rf: 0.48 (m²·K)/W Floor slab surface area, A: 1296.89 m² Floor slab perimeter, P: 192.274 m Thermal conductivity, λ: 2.000 W/(m·K)
2.3 Internal vertical partitioning	
Basic wall MW 120	 Layer list: 1 - Plaster 1.50 cm 2 - Brick 9.00 cm 3 - Plaster 1.50 cm Properties Thermal transmittance, U: 1.33 W/(m²·K) Total thickness 12.00 cm
IW STB 380	 Layer list: 1 - Plaster 1.50 cm 2 - Eq. masonry 35.00 cm 3 - Plaster 1.50 cm Properties Thermal transmittance, U: 0.86 W/(m²·K) Total thickness 38.00 cm
IW STB 500	 Layer list: 1 - Plaster 1.50 cm 2 - Eq. masonry 47.00 cm 3 - Plaster 1.50 cm Properties Thermal transmittance, U: 0.67 W/(m²·K) Total thickness 50.00 cm

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

Table 5: Construction systems

3.1 Façade openings	
Main entrance door	Heat transfer coefficient (U): 3.00 W/(m²·K) Absorptance: 0.6
3.2 Windows	
Standard Floor Window	Thermal transmittance, U: 5.72 W/(m²·K) Solar factor, g: 0.950 Opaque fraction, Ff: 0.200
THF Speisesaal EG	Thermal transmittance, U: 5.72 W/(m²·K) Solar factor, g: 0.950 Opaque fraction, Ff: 0.200

2.2.2 HVAC systems

Regarding the HVAC systems, the building is characterized by central heating systems. The whole building is equipped with a district heating for heating and 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	Office spaces
Reference name	District heating
Year of installation	n.a.
Location of the generator	Central location
Rated capacity [kW]	-
Average seasonal efficiency	1
Energy fuel	Natural gas
Supply/return [°C]	80/60
Terminal units	Radiators

2.2.3 Occupancy, lighting, equipment, and operating patterns

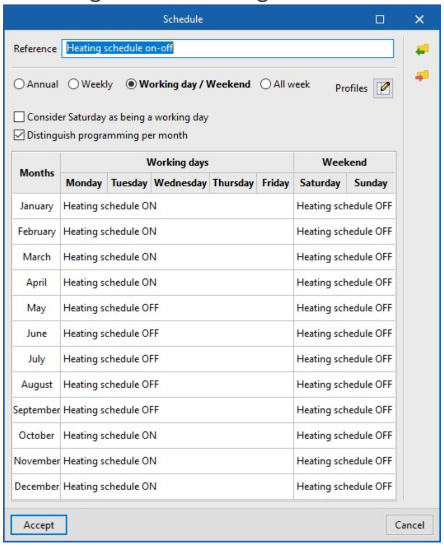
Tempelhof BEM has been characterised also from the point of view of the internal gains as summarised in the following table 7.

Table 7: Internal gains features

OCCUPIED Space	Ventilation rates	LIGHTING Installed power	EQUIPMENT Installed power	PEOPLE	ACTIVITY level
All Office floors	8.50 (l/s)person	8.8 W/mq	10.80 W/mq	20 mq/person	130 W/person

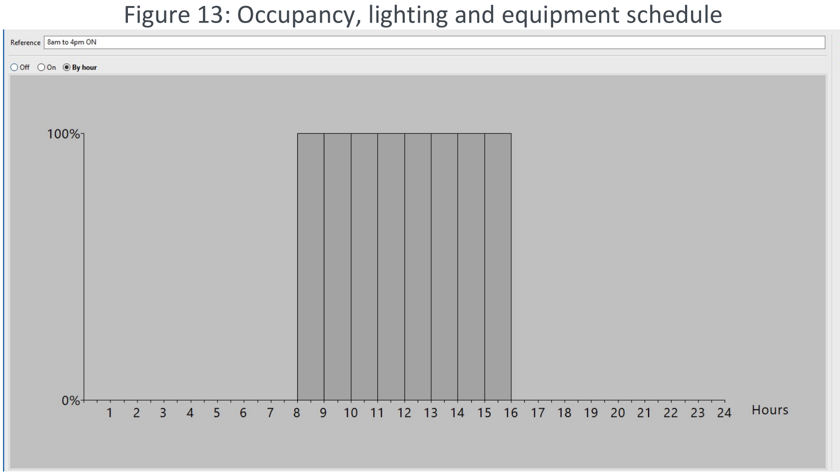
Relevant operating schedules and occupational patterns have been assumed based on standard office space type and on a few information collected from the users. Following figures show a few of the patterns set for the Tempelhof BEM.

Figure 12: Heating schedule



Months	Working days					Weekend	
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	Heating schedule ON					Heating schedule OFF	
February	Heating schedule ON					Heating schedule OFF	
March	Heating schedule ON					Heating schedule OFF	
April	Heating schedule ON					Heating schedule OFF	
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 ON					Heating schedule OFF	
November	Heating schedule ON					Heating schedule OFF	
December	Heating schedule ON					Heating schedule OFF	

Figure 13: Occupancy, lighting and equipment schedule



3. BEM calibration

The BEM has not been calibrated with the BIM SPEED new procedure (sufficiently detailed data were not available from both the energy bills side and the energy model side).

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 1.18 – 1.41 W/mqK, and windows characterized by thermal transmittance of 5.72 W/mqK.

4.2 Energy KPIs

The following Energy KPI has 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 the consumption point and multiplied by the conversion factor (specific for Germany) for final energy to primary energy. The table below summarises the primary energy demand related to natural gas and network electricity.

Table 8: BS.OPED Operational Primary Energy Demand

BS.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	162.98

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Natural gas	497635.71	99.97	1.195	594674.68	119.47
Electricity obtained from the network	91463.54	18.37	2.368	216585.66	43.51

where:

- C_{ef}: *Energy consumption at consumption point (final energy), kWh/m²·yea*
- 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 Tempelhof demo)

Table 9: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	99.5
Q_{DHW} [kWh/m²year]	0.4
Q_{TOT} [kWh/m²year]	**100**

		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 = 4977.78 m²; V = 17775.43 m³)															
Energy demand	Heating	107806.3	91029.7	65424.8	39329.0	--	--	--	--	--	34733.5	68445.9	88660.6	495429.8	99.5
	DHW	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	TOTAL	107993.7	91198.9	65612.1	39510.3	187.4	181.3	187.4	187.4	181.3	34920.8	68627.2	88848.0	497635.7	100.0

BS.TEC: Total Energy Consumption

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

Table 10: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	118.9
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	43.5
EP_{dhw}[kWh/m²]	0.5
EP_{TOT}[kWh/m²]	**162.9**

		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 = 4977.78 m²; V = 17775.43 m³)															
Energy demand	**Heating**	**107806.3**	**91029.7**	**65424.8**	**39329.0**	--	--	--	--	--	**34733.5**	**68445.9**	**88660.6**	**495429.8**	**99.5**
	DHW	**187.4**	**169.2**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**2205.9**	**0.4**
	TOTAL	**107993.7**	**91198.9**	**65612.1**	**39510.3**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**34920.8**	**68627.2**	**88848.0**	**497635.7**	**100.0**
Natural gas (f_{cep} = 1.189)	EF_{heat}	107806.3	91029.7	65424.8	39329.0	--	--	--	--	--	34733.5	68445.9	88660.6	495429.8	99.5
	EP_{heat}	128828.5	108780.5	78182.6	46998.2	--	--	--	--	--	41506.5	81792.9	105949.5	592038.6	118.9
	$EP_{nr,heat}$	**128184.4**	**108236.6**	**77791.7**	**46763.2**	--	--	--	--	--	**41299.0**	**81383.9**	**105419.7**	**589078.4**	**118.3**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	EP_{dhw}	223.9	202.2	223.9	216.7	223.9	216.7	223.9	223.9	216.7	223.9	216.7	223.9	2636.1	0.5
	$EP_{nr,dhw}$	**222.8**	**201.2**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**2622.9**	**0.5**
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}	8060.0	7008.7	7709.6	7359.1	8060.0	7359.1	7709.6	8060.0	7008.7	8060.0	7709.6	7359.1	91463.5	18.4
	EP_{light}	19086.1	16596.6	18256.3	17426.4	19086.1	17426.4	18256.3	19086.1	16596.6	19086.1	18256.3	17426.4	216585.7	43.5
	$EP_{nr,light}$	**15749.8**	**13695.5**	**15065.1**	**14380.3**	**15749.8**	**14380.3**	**15065.1**	**15749.8**	**13695.5**	**15749.8**	**15065.1**	**14380.3**	**178726.5**	**35.9**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**116053.7**	**98207.6**	**73321.7**	**46869.4**	**8247.4**	**7540.4**	**7896.9**	**8247.4**	**7190.0**	**42980.9**	**76336.8**	**96207.1**	**589099.2**	**118.3**
	C_{ep}	**148138.5**	**125579.3**	**96662.7**	**64641.3**	**19310.0**	**17643.1**	**18480.1**	**19310.0**	**16813.3**	**60816.5**	**100265.8**	**123599.8**	**811260.3**	**163.0**
	$C_{ep,nr}$	**144157.0**	**122133.3**	**93079.5**	**61359.0**	**15972.6**	**14595.9**	**15287.8**	**15972.6**	**13911.1**	**57271.6**	**96664.6**	**120022.8**	**770427.8**	**154.8**

where:

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

5. Building renovation scenarios

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 by changing the relevant parameters within the Calibrated Model.

5.1 Renovation scenarios proposed

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

Table 11: Overview of the Tempelhof Renovation Scenarios

	External Wall insulation	Roof insulation	Windows replacement	Heating System replacement	Floor insulation	Additional Energy Source
Scenario 01	ETICS	+ Grafipol	Energy 82 mm - PVC	-	+ Grafipol	-
Scenario 02	ETICS	+ Grafipol	-	-	-	-
Scenario 03	Ventilated	+ Grafipol	Energy 82 mm - PVC	-	+ Grafipol	Photovoltaic

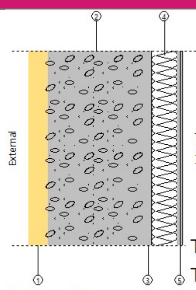
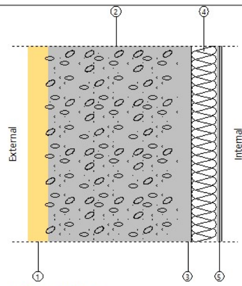
5.2 Scenario 1: description and results

In scenario 1, the following interventions has been analysed:

1. An insulation layer made up of EPS Grafipol TR 31 (thickness 0.08 m and thermal conductivity 0.031 W/mK) was added on the external side of the external walls.
2. An insulation layer made up of EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added on the internal side of the roof.
3. All the existing windows were replaced with new pvc windows (Energy 82 mm - PVC) with a glazing heat transfer coefficient Uw of 0.79 W/m^{2}K.
4. An insulation layer made up of EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added on the internal side of each floor slab.

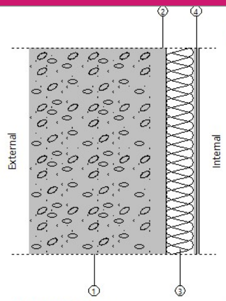
The following table summarises the new construction systems.

Table 12: Construction systems

1.1 Façades	
Basic wall STB 380 (38.00 cm) + internal insulation	 Layer list: 1 - Facade shel limestone 6.00 cm 2 - Eq. Brick wall 30.00 cm 3 - Plaster 2.00 cm 4 - Poliestireno expandido (EPS) 8.00 cm 5 - Gypsum board 1.50 cm Thermal transmittance, U: 0.17 W/(m^2·K) Total thickness 38.00 cm Properties Thermal transmittance, U: 0.28 W/(m^2·K) Total thickness 47.50 cm
Basic wall STB 500 (50.00 cm) + internal insulation	 Layer list: 1 - Facade shel limestone 6.00 cm 2 - Eq. Brick wall 42.00 cm 3 - Plaster 2.00 cm 4 - Poliestireno expandido (EPS) 8.00 cm 5 - Gypsum board 1.50 cm Properties Thermal transmittance, U: 0.27 W/(m^2·K) Total thickness 59.50 cm

1.2 Walls in contact with soil

BW STB 400 + internal insulation

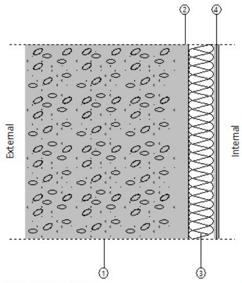


Layer list:

1 -	Eq. Brick wall	38.00 cm
2 -	Plaster	2.00 cm
3 -	Poliestireno expandido (EPS)	8.00 cm
4 -	Gypsum board	1.50 cm

Properties
Thermal transmittance, U: 0.13 W/(m²·K)
Total thickness 49.50 cm

BW STB 500 + internal insulation



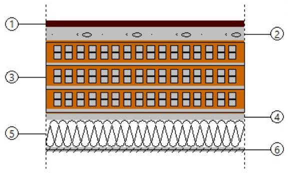
Layer list:

1 -	Eq. Brick wall	48.00 cm
2 -	Plaster	2.00 cm
3 -	Poliestireno expandido (EPS)	8.00 cm
4 -	Gypsum board	1.50 cm

Properties
Thermal transmittance, U: 0.13 W/(m²·K)
Total thickness 59.50 cm

2.1 Roof

Roof slab (30.00cm) + internal insulation



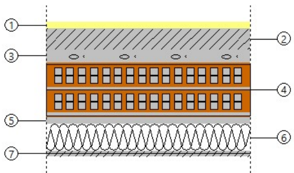
Layer list:

1 -	Bitumen membrane	2.00 cm
2 -	Concrete	4.00 cm
3 -	Eq. floor slab	22.00 cm
4 -	Plaster	2.00 cm
5 -	EPS Grafipol TR 32	8.00 cm
6 -	Plasterboard	1.50 cm

Properties
Thermal transmittance, U: 0.28 W/(m²·K)
Total thickness 39.50 cm

2.2 Internal horizontal partitioning

Hochlsteindecke 300 (30.00 cm) + internal insulation



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
6 -	EPS Grafipol TR 32	8.00 cm
7 -	Plasterboard	1.50 cm

Properties
Thermal transmittance, U: 0.30 W/(m²·K)
Total thickness 39.50 cm

3.1 Windows

New windows	Uw=0.79 W/m²K

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 13: BS.OPED Operational Primary Energy Demand

S1.OPED: Operational Primary Energy Demand	
Ep [kWh/m^2]	95.11

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Natural gas	214931.24	43.18	1.195	256842.83	51.60
Electricity obtained from the network	91463.54	18.37	2.368	216585.66	43.51

BS.TED: Total Energy Demand

Table 14: BS.TED Total Energy Demand

S1.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m^{2}year]	42.7
Q_{DHW} [kWh/m^{2}year]	0.4
Q_{TOT} [kWh/m^{2}year]	**43.2**

		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 = 4977.78 m²; V = 17775.43 m³)															
	Heating	49575.6	42338.9	27830.6	15179.3	--	--	--	--	--	9735.7	28154.2	39911.0	212725.3	42.7
Energy demand	DHW	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	TOTAL	49763.0	42508.1	28017.9	15360.6	187.4	181.3	187.4	187.4	181.3	9923.0	28335.6	40098.3	214931.2	43.2

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

Table 15: BS.TEC Total Energy Consumption

S1.TEC: Total Energy Consumption	
EP_{heat}[kWh/m^2]	51.1
EP_{cool}[kWh/m^2]	Cooling not present
EP_{light}[kWh/m^2]	43.5
EP_{dhw}[kWh/m^2]	0.5
EP_{TOT}[kWh/m^2]	**95.1**

		Jan (kWh)	Feb (kWh)	Mar (kWh)	Apr (kWh)	May (kWh)	Jun (kWh)	Jul (kWh)	Aug (kWh)	Sep (kWh)	Oct (kWh)	Nov (kWh)	Dec (kWh)	Year (kWh/year)	Year (kWh/m²·year)
BUILDING (S_u = 4977.78 m²; V = 17775.43 m³)															
Energy demand	**Heating**	**49575.6**	**42338.9**	**27830.6**	**15179.3**	--	--	--	--	--	**9735.7**	**28154.2**	**39911.0**	**212725.3**	**42.7**
	DHW	**187.4**	**169.2**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**2205.9**	**0.4**
	TOTAL	**49763.0**	**42508.1**	**28017.9**	**15360.6**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**9923.0**	**28335.6**	**40098.3**	**214931.2**	**43.2**
Natural gas (f_{ep} = 1.189)	EF_{heat}	49575.6	42338.9	27830.6	15179.3	--	--	--	--	--	9735.7	28154.2	39911.0	212725.3	42.7
	EP_{heat}	59242.9	50595.0	33257.5	18139.3	--	--	--	--	--	11634.2	33644.3	47693.6	254206.7	51.1
	$EP_{nr,heat}$	**58946.7**	**50342.0**	**33091.2**	**18048.6**	--	--	--	--	--	**11576.0**	**33476.1**	**47455.1**	**252935.7**	**50.8**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	EP_{dhw}	223.9	202.2	223.9	216.7	223.9	216.7	223.9	223.9	216.7	223.9	216.7	223.9	2636.1	0.5
	$EP_{nr,dhw}$	**222.8**	**201.2**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**2622.9**	**0.5**
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}	8060.0	7008.7	7709.6	7359.1	8060.0	7359.1	7709.6	8060.0	7008.7	8060.0	7709.6	7359.1	91463.5	18.4
	EP_{light}	19086.1	16596.6	18256.3	17426.4	19086.1	17426.4	18256.3	19086.1	16596.6	19086.1	18256.3	17426.4	216585.7	43.5
	$EP_{nr,light}$	**15749.8**	**13695.5**	**15065.1**	**14380.3**	**15749.8**	**14380.3**	**15065.1**	**15749.8**	**13695.5**	**15749.8**	**15065.1**	**14380.3**	**178726.5**	**35.9**
Auto-consumed electricity (f_{ep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$C_{ef,total}$	**57823.0**	**49516.8**	**35727.5**	**22719.7**	**8247.4**	**7540.4**	**7896.9**	**8247.4**	**7190.0**	**17983.1**	**36045.1**	**47457.4**	**306394.8**	**61.6**
	C_{ep}	**78552.9**	**67393.8**	**51737.7**	**35782.4**	**19310.0**	**17643.1**	**18480.1**	**19310.0**	**16813.3**	**30944.1**	**52117.3**	**65343.9**	**473428.5**	**95.1**
	$C_{ep,nr}$	**74919.3**	**64238.7**	**48379.1**	**32644.4**	**15972.6**	**14595.9**	**15287.8**	**15972.6**	**13911.1**	**27548.6**	**48756.8**	**62058.2**	**434285.1**	**87.2**

where:

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

BS.TES: Total Energy savings

Table 16: BS.TES Total Energy Savings

S1.TES: Total Energy Savings			
	Baseline	**Scenario 01**	**SAVING**
EP_{heat}[kWh/m²]	118.9	51.1	67.8
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	43.5	43.5	0
EP_{dhw}[kWh/m²]	0.5	0.5	0
EP_{TOT}[kWh/m²]	**162.9**	**95.1**	**67.8**

5.3 Scenario 2: description and results

Scenario 2 is like scenario 1 with the internal insulation of the external walls and roof. There are two differences: the windows and the internal floor slabs are kept as the pre-existing ones.

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 17: BS.OPED Operational Primary Energy Demand

S2.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	107.53

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Natural gas	266683.64	53.57	1.195	318686.95	64.02
Electricity obtained from the network	91463.54	18.37	2.368	216585.66	43.51

BS.TED: Total Energy Demand

Table 18: BS.TED Total Energy Demand

S2.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	53.1
Q_{DHW} [kWh/m²year]	0.4
Q_{TOT} [kWh/m²year]	**53.6**

		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 = 4977.78 m²; V = 17775.43 m³)															
Energy demand	Heating	60568.0	51479.1	34280.0	19415.4	--	--	--	--	--	14183.1	35327.0	49225.0	264477.7	53.1
	DHW	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	TOTAL	60755.3	51648.3	34467.4	19596.7	187.4	181.3	187.4	187.4	181.3	14370.4	35508.4	49412.4	266683.6	53.6

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

Table 19: BS.TEC Total Energy Consumption

S2.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	63.5
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	43.5
EP_{dhw}[kWh/m²]	0.5
EP_{TOT}[kWh/m²]	**107.5**

BS.TES: Total Energy savings

Table 20: BS.TES Total Energy Savings

S2.TES: Total Energy Savings			
	Baseline	Scenario 02	SAVING
EP_{heat}[kWh/m²]	118.9	63.5	55.4
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	43.5	43.5	0
EP_{dhw}[kWh/m²]	0.5	0.5	0
EP_{TOT}[kWh/m²]	**162.9**	**107.5**	**55.4**

5.4 Scenario 3: description and results

In scenario 3, the following interventions have been analysed:

1. An insulation layer made up of EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added on the internal side of the roof (Same as scenarios 1 and 2).
2. All the existing windows were replaced with new pvc windows (Energy 82 mm - PVC) with a glazing heat transfer coefficient Uw of 0.79 W/m2K. (Same as scenario 1).
3. An insulation layer made up of EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mK) was added on the internal side of each floor slab. (Same as scenario 1)
4. An insulation layer made up of Rockwool (thickness 0.08 m and thermal conductivity 0.034 W/mK) and air gap was added on the external side of the external walls and makes it as a ventilated wall.
5. Photovoltaic Solar panels (450wp SUNERGY, 2108×1048×35) were added with a total power installed of 18kW. They have the potential of producing 19045.0 kWh/year.

The following KPIs have been calculated:

BS.OPED: Operational Primary Energy Demand

Table 21: BS.OPED Operational Primary Energy Demand

S3.OPED: Operational Primary Energy Demand	
Ep [kWh/m²]	87.32

Energy vector	C_{ef} (kWh/year)	C_{ef} (kWh/m²·year)	f_{cep}	C_{ep} (kWh/year)	C_{ep} (kWh/m²·year)
Naturalgas	204275.70	41.04	1.195	244109.46	49.04
Electricityobtainedfromthenetwork	72418.54	14.55	2.368	171487.10	34.45
Electricityproducedonsite(renewable)	19045.00	3.83	1.000	19045.00	3.83

BS.TED: Total Energy Demand

Table 22: BS.TED Total Energy Demand

S3.TED: Total Energy Demand	
$Q_{HEATING}$ [kWh/m²year]	40.6
Q_{DHW} [kWh/m²year]	0.4
Q_{TOT} [kWh/m²year]	**41.0**

		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 = 4977.78 m²; V = 17775.43 m³)															
Energy demand	**Heating**	47561.7	40757.3	26699.3	14193.6	--	--	--	--	--	7981.2	26731.6	38145.1	202069.8	40.6
	DHW	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	TOTAL	47749.1	40926.5	26886.7	14374.9	187.4	181.3	187.4	187.4	181.3	8168.5	26912.9	38332.5	204275.7	41.0

S3.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 23: BS.TEC Total Energy Consumption

S3.TEC: Total Energy Consumption	
EP_{heat}[kWh/m²]	48.5
EP_{cool}[kWh/m²]	Cooling not present
EP_{light}[kWh/m²]	43.5
EP_{dhw}[kWh/m²]	0.5
EP_{solar}[kWh/m²]	-9.1
EP_{TOT}[kWh/m²]	**83.4**

		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 = 4977.78 m²; V = 17775.43 m³)															
Energy demand	**Heating**	**47561.7**	**40757.3**	**26699.3**	**14193.6**	--	--	--	--	--	**7981.2**	**26731.6**	**38145.1**	**202069.8**	**40.6**
	DHW	**187.4**	**169.2**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**187.4**	**181.3**	**187.4**	**2205.9**	**0.4**
	TOTAL	**47749.1**	**40926.5**	**26886.7**	**14374.9**	**187.4**	**181.3**	**187.4**	**187.4**	**181.3**	**8168.5**	**26912.9**	**38332.5**	**204275.7**	**41.0**
Naturalgas (f_{cep} = 1.189)	EF_{heat}	47561.7	40757.3	26699.3	14193.6	--	--	--	--	--	7981.2	26731.6	38145.1	202069.8	40.6
	EP_{heat}	56836.2	48704.9	31905.7	16961.3	--	--	--	--	--	9537.5	31944.2	45583.4	241473.4	48.5
	$EP_{nr,heat}$	**56552.1**	**48461.4**	**31746.1**	**16876.5**	--	--	--	--	--	**9489.8**	**31784.5**	**45355.5**	**240266.0**	**48.3**
	EF_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EP_{cool}	--	--	--	--	--	--	--	--	--	--	--	--	--	
	$EP_{nr,cool}$	--	--	--	--	--	--	--	--	--	--	--	--	--	
	EF_{dhw}	187.4	169.2	187.4	181.3	187.4	181.3	187.4	187.4	181.3	187.4	181.3	187.4	2205.9	0.4
	EP_{dhw}	223.9	202.2	223.9	216.7	223.9	216.7	223.9	223.9	216.7	223.9	216.7	223.9	2636.1	0.5
	$EP_{nr,dhw}$	**222.8**	**201.2**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**222.8**	**215.6**	**222.8**	**215.6**	**222.8**	**2622.9**	**0.5**
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}	8060.0	7008.7	7709.6	7359.1	8060.0	7359.1	7709.6	8060.0	7008.7	8060.0	7709.6	7359.1	91463.5	18.4
	EP_{light}	19086.1	16596.6	18256.3	17426.4	19086.1	17426.4	18256.3	19086.1	16596.6	19086.1	18256.3	17426.4	216585.7	43.5
	$EP_{nr,light}$	**15749.8**	**13695.5**	**15065.1**	**14380.3**	**15749.8**	**14380.3**	**15065.1**	**15749.8**	**13695.5**	**15749.8**	**15065.1**	**14380.3**	**178726.5**	**35.9**
Auto-consumed electricity (f_{cep} = 1.954)	EF	--	--	--	--	--	--	--	--	--	--	--	--	-19045.0	-3.8
	EP	--	--	--	--	--	--	--	--	--	--	--	--	-45098.6	-9.1
	EP_{nr}	--	--	--	--	--	--	--	--	--	--	--	--	-37215.3	-7.5
	$C_{ef,total}$	**55809.1**	**47935.2**	**34596.2**	**21734.0**	**8247.4**	**7540.4**	**7896.9**	**8247.4**	**7190.0**	**16228.5**	**34622.4**	**45691.6**	**276694.2**	**55.6**
	C_{ep}	**76146.2**	**65503.8**	**50385.8**	**34604.4**	**19310.0**	**17643.1**	**18480.1**	**19310.0**	**16813.3**	**28847.5**	**50417.1**	**63233.8**	**415596.6**	**83.5**
	$C_{ep,nr}$	**72524.7**	**62358.1**	**47034.0**	**31472.4**	**15972.6**	**14595.9**	**15287.8**	**15972.6**	**13911.1**	**25462.4**	**47065.1**	**59958.6**	**384400.1**	**77.2**

where:

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

BS.TES: Total Energy savings

Table 24: BS.TES Total Energy Savings

S3.TES: Total Energy Savings			
Baseline		**Scenario 03**	**SAVING**
EP_{heat}[kWh/m²]	118.9	48.5	70.4
EP_{cool}[kWh/m²]	Cooling not present		
EP_{light}[kWh/m²]	43.5	43.5	0
EP_{dhw}[kWh/m²]	0.5	0.5	0
EP_{solar}[kWh/m²]		-9.1	9.1
EP_{TOT}[kWh/m²]	**162.9**	**83.4**	**79.5**

6. Time reduction evaluation

Following table shows the results of the time reduction for the Tempelhof 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 the energy modeler 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)		4	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, …)		1	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)		3	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)	2
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: 41%				