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List of Abbreviations

ACS	Air Conditioning System
AEC	Architecture, Engineering and Construction
ARIBFA	Augmented Reality Enabled in-situ Building Feature Annotation
BEP	Building Energy Performance
BICA	Building Information Collection Application
BIF	BIMERR Interoperability Framework
BIM	Building Information Modelling
BIM-MP	BIMERR – Management Platform
BPMN	Business Process Model and Notation
CO2	Carbon dioxide
CPU	central processing unit (CPU)
CT	Cost Time
DS	Demonstration Scenario
ECM	Energy Conservation Measure
EPW	EnergyPlus weather data file
GUID	Global Unique Identifier
H&S	Health and Safety
HDL	Hardware description language
HVAC	Heating Ventilation and Air Conditioning
IFC	Industry Foundation Classes
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
KPI	Key Performance Indicator
LCA	Life cycle assessment
LCC	life cycle costing
LED	Light-Emitting Diode
MET	eMule Resource Files
ObXML	Occupant Behaviour XML
PRUBS	Profiling Residents Usage of Building Systems
PVC	Polyvinyl chloride
PWMA	Process & Workflow Modelling and Automation
RenoDSS	Renovation Decision Support System
RMSE	Root Mean Square Error
SUS	system usability scale
TLS	Terrestrial Laser Scanning
TMY	Typical Meteorological Year
UA	User Acceptance
UC	Use Case
UI	User Interface
WSN	Wireless Sensor Network
XML	eXtensible Markup Language

EXECUTIVE SUMMARY

This deliverable includes the activities related to the selection and analysis of the renovation projects to be used as demonstration testbeds, as well as the necessary preparations for the BIMERR tool evaluation. Initially, two renovation projects (one in Spain and one in Poland) with timeline and scope matching the BIMERR requirements were selected by the pilot partners in Spain and Poland. In this deliverable their characteristics such as Building Geometry, Building Materials and Construction, Heating, Ventilation and Air Conditioning (HVAC), Other Energy Usage Equipment and Internal Gains, Climate data, and BIMERR input data requirements, are described. The renovation goals along with the high-level Gantt charts are also presented for both pilot sites in order to provide the basis for the planning and scheduling of all the activities that relate to the five demonstration scenarios that are based on the five business scenarios described in D3.1 [1].

It should be mentioned here that for the Polish pilot site, the final list of renovation measures, the corresponding final Gantt and the necessary adjustments and changes will be provided by the pilot partner after finalization of the required public order and tender processes for renovation This information along with relevant amendments will be included in an updated and final version of the deliverable.

The evaluation methodology described in D3.3 [2] is now tailored to the specific pilot sites and renovation projects and hence, it is fine-tuned to match the specific renovation goals for each site. Therefore, all the Key Performance Indicators (KPIs) used to assess and demonstrate BIMERR objectives in terms of cost and time, energy, and user acceptance along with the baselining process are filtered following an iterative process that involved the BIMERR tool developers and a feedback loop with the pilot partners that provided the necessary updates on the pilot projects.

Finally, the Wireless Sensor Network (WSN) infrastructure is employed to collect measurements for energy and profiling of resident behaviour related data, while lessons learned during the pre-validation activities of T8.4 are also included here to ensure that risks are mitigated during the planning and execution of the real demonstration activities.

INTRODUCTION

The objectives of this deliverable include the selection and analysis of two renovation projects (one in Poland and one in Spain), the evaluation methodology fine tuning to target the specific characteristics of the pilot buildings and the planning and scheduling of the demonstration/evaluation activities. In order to address these objectives, the structure of the deliverable includes three main sections.

In the first section the BIMERR pilots are described, and hence there are separate subsections for the Polish and the Spanish pilot sites that include information for the following:

- Building geometry
- Building materials and construction
- Heating, ventilation, and air conditioning
- Other energy usage equipment and internal gains
- Climate data
- BIMERR input data requirements
    - 3D scanning
    - BIM model in Revit and IFC exportation
    - Visual Data – Images
    - Sensing, Monitoring and Metering Data
    - Weather Data Files – Typical Meteorological Year and Actual Data
    - Cost - Time Baseline data requirements
    - Energy Baseline Data Requirements
    - Renovation measures that will be implemented
- High level Gantt for the renovation measures

In the second section we describe the BIMERR pilot specific evaluation methodology that considers the main categories of interest such as renovation total time and cost requirements, energy efficiency, user acceptance, sustainability, and economic potential. The KPIs that have been defined in order to report BIMERR performance towards these categories of interest in D3.3, were then filtered by the BIMERR tool developers and the pilot partners, when the pilot projects were selected (M24), and a high-level description of the buildings was made available. This filtering process resulted in updates (removals, additions, modifications) that are presented in this section.

Finally, in the third section of this deliverable, the BIMERR tools activities for the two pilots are described in the context of the demonstration scenarios that are based on the five business scenarios described in D3.1 [1]. First the conclusions from the pre-validation phase in terms of lessons learned for each BIMERR tool, provides valuable feedback for better planning the demo activities, and hence, are presented. Then, for each of the five demonstration scenarios, information for (a) the BIMERR components that are deployed, (b) the enablers and potential blockers that are identified at this point and (c) the KPIs considered, is provided. Finally, the realisation of each demonstration scenario is considered with a respective test case plan based on the information known for the pilot sites.

1 BIMERR Pilots

1.1 Renovation Goals

In the Polish pilot site, the main objective is to improve the energy characteristic of a social double segment residential building. The base scenario of renovation focuses on two main aspects: the first one provides a new external insulation on facades which will improve thermal resistance, while the second element of renovation will be replacing windows on the basement level, to seal the building and prevent thermal energy loss.

In the Spanish pilot site, the main objective is to improve the energy characteristics of a residential tower-building according to previous Energy Performance Certificate standards, from class G to class C. The overall goal is to improve the thermal insulation, with a reduction of the façade transmittance, hence reducing the energy demand of the building. In addition to the improvement of the envelope of the building, a partial improvement of the existing heating installations will take place. The exact renovation measures are described in the deliverable.

1.2 Polish Building

The Polish pilot building is located in Poland's capital Warsaw, which is part of central Poland and the Mazovia region. The address of the building is: 15, Wiarusów Str, 04-290 Warsaw, South Praga. The longitude and latitude are 52.243501 and 21.115502, respectively. Fig. 1-1 depicts the area where the building is located, Table 1-1 contains its main characteristics and Fig. 1-2 shows external views of the building.

The building was constructed in 1995 in the South Praga district in the surrounding of post-industrial buildings. In 1995, the area of south Praga was re-developed by the city to host residential building space.

The building is owned by the Department of Real Estate Management of Warsaw city, and it is used as a communal building in order to support citizens and their families, with financial difficulties.

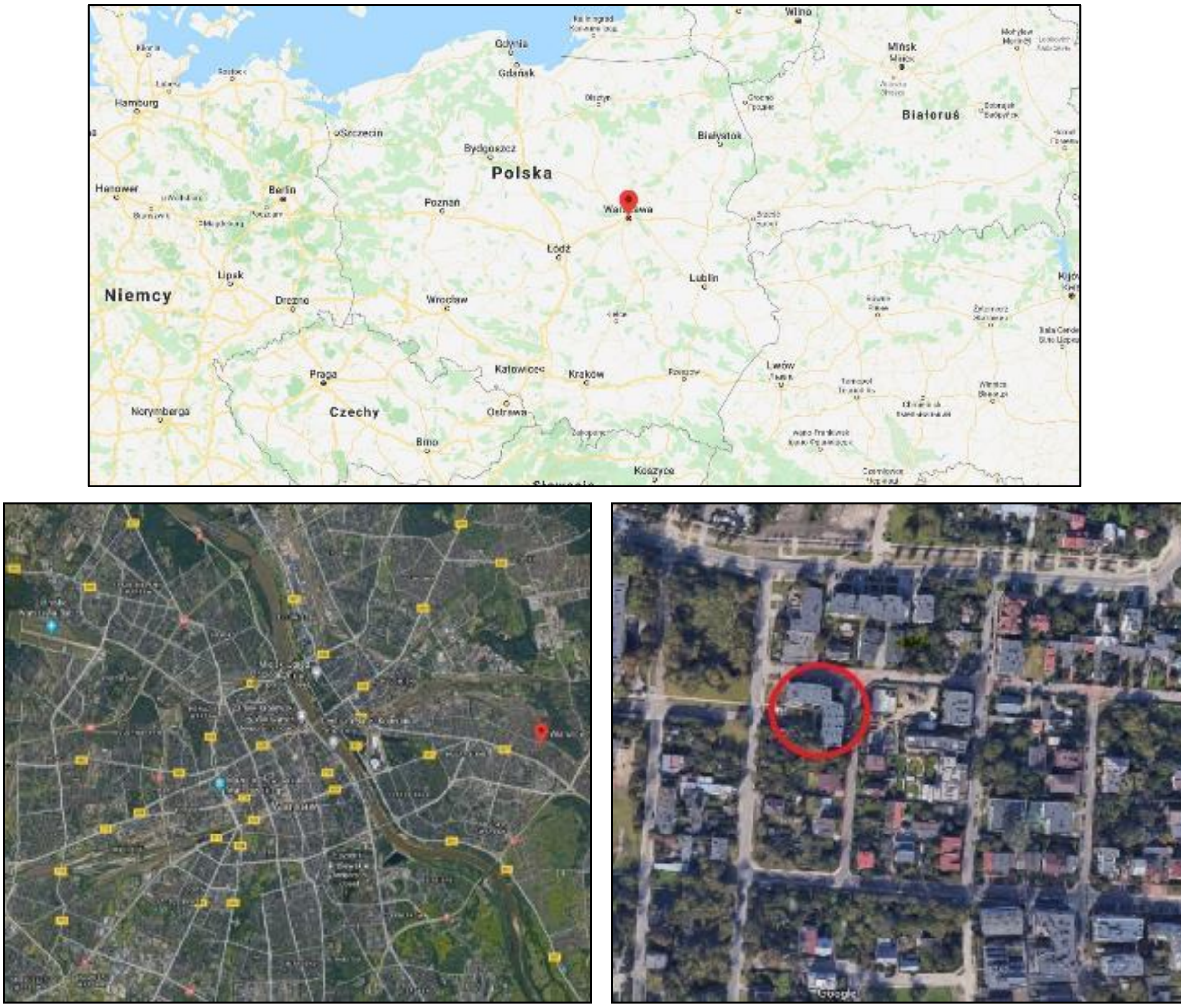


Fig. 1-1: Location of the Polish pilot building (Source: Google Maps)

Building area (m2)	838,40
Net Building Volume (m3)	6195,50
Gross heated volume (m3)	9394,40
Floor area of apartments (m2)	2190,20
Floor area of other heated area (m2)	288,00
Net heated building area (m2)	2478,20
Number of staircases	4
Number of floors	4 + basement
Floor height (m)	2,3/2,5
Number of tenants	120
Number of apartments	64
Type of heating	Central heating
SA:V ratio	0.39

Table 1-1: Main building characteristics.

Fig. 1-2: Exterior views of the Polish pilot building

1.2.1 Building Geometry

In this section, the relevant information about the building geometry is summarized and visually illustrated with Fig. 1-3 and Fig. 1-4.

The facade was measured with a laser device as part of the site analysis regarding the geometric parameters of the building. In addition, an internal and external review of the pilot building was conducted with indicators dividing and defining particular building segments, dwellings, and internal dwelling spaces. Fig. 1-4 "I" and "II" indicate both building segments, while "A" till "O" indicate each apartment, (for example "IA" refers to a dwelling located in the first segment of the building, South – West part).

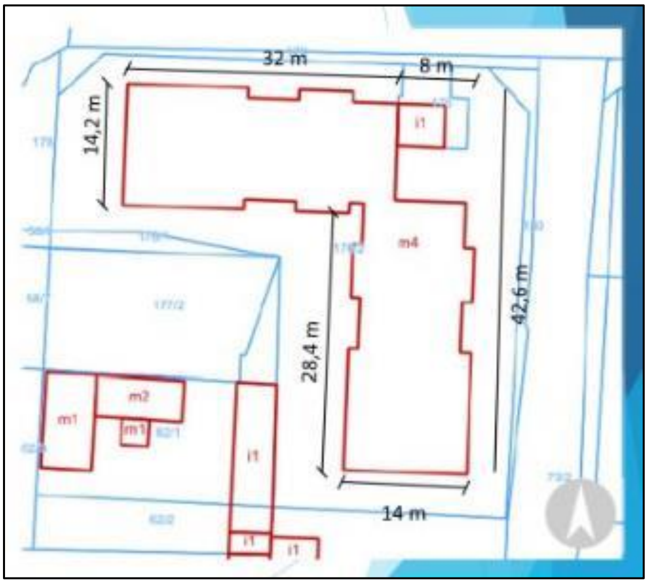


Fig. 1-3: Building external geometry

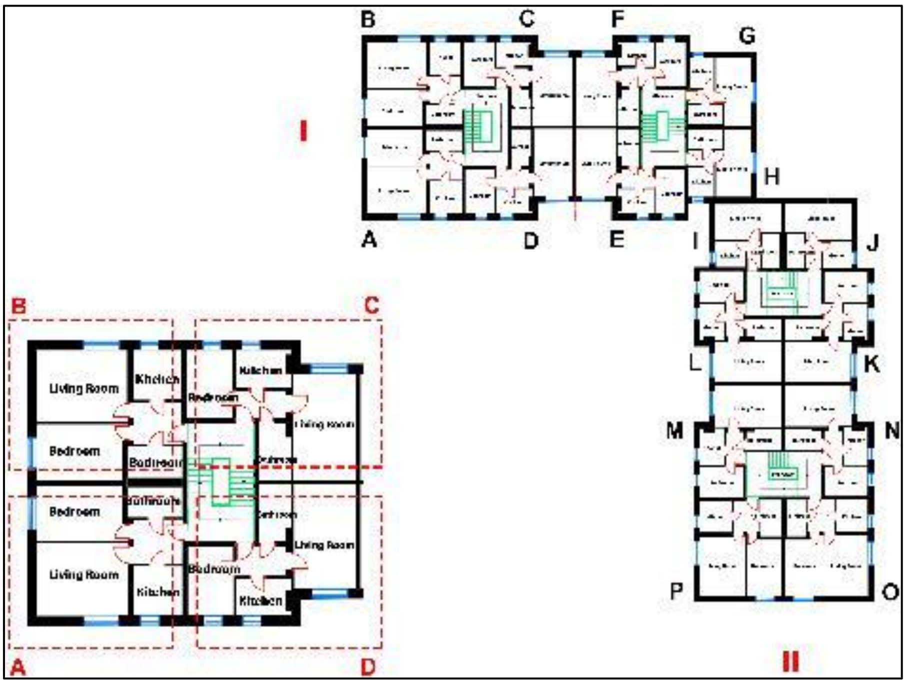


Fig. 1-4: Internal geometry

1.2.2 *Building Materials and Construction*

Based on the energy audit, the Polish partner obtained more detailed information about the building materials. In this section each building element is described according to the existing on-site data.

The upper slabs are made of reinforced concrete, pre-fabricated, made of hollow core slabs. The floor slab above basement is thermally insulated with expanded polystyrene of thickness of 8 cm. The roof slab is ventilated, made of prefabricated, reinforced concrete, hollow core slabs thermally insulated with mineral wool (10 cm thickness).

Table 1-2 to Table 1-10 gather the main materials and their properties for the basement and roof slabs (see also Fig. 1-5 and Fig. 1-13), the slab above the basement (see Fig. 1-6), the section slab S01 (see Fig. 1-7), the bathroom slab (see Fig. 1-8), the section slab S03 (see Fig. 1-9), the external basement wall (see also Fig. 1-10), the external wall section EW02 (see also Fig. 1-11), and the external wall section EW03 (see also Fig. 1-12).

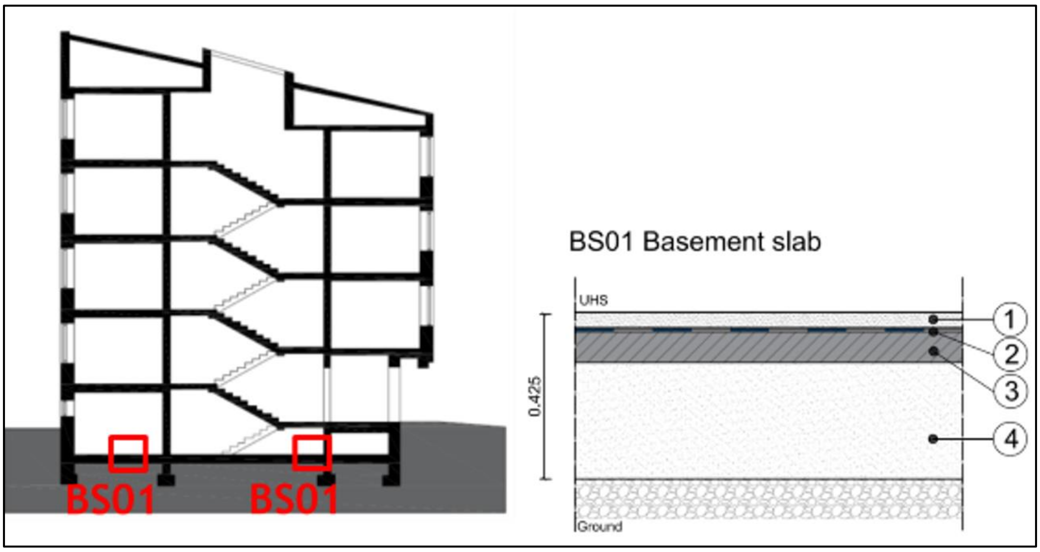


Fig. 1-5: Basement slab sections

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m^3)
Cemented screed	4	1,4	0,84	2000
Double bitumen membrane	0,3	0,18	1,6	-
Lean concrete	8	1,6	0,84	1800
Sand blinding	30	-	-	-

Table 1-2: Basement slab materials

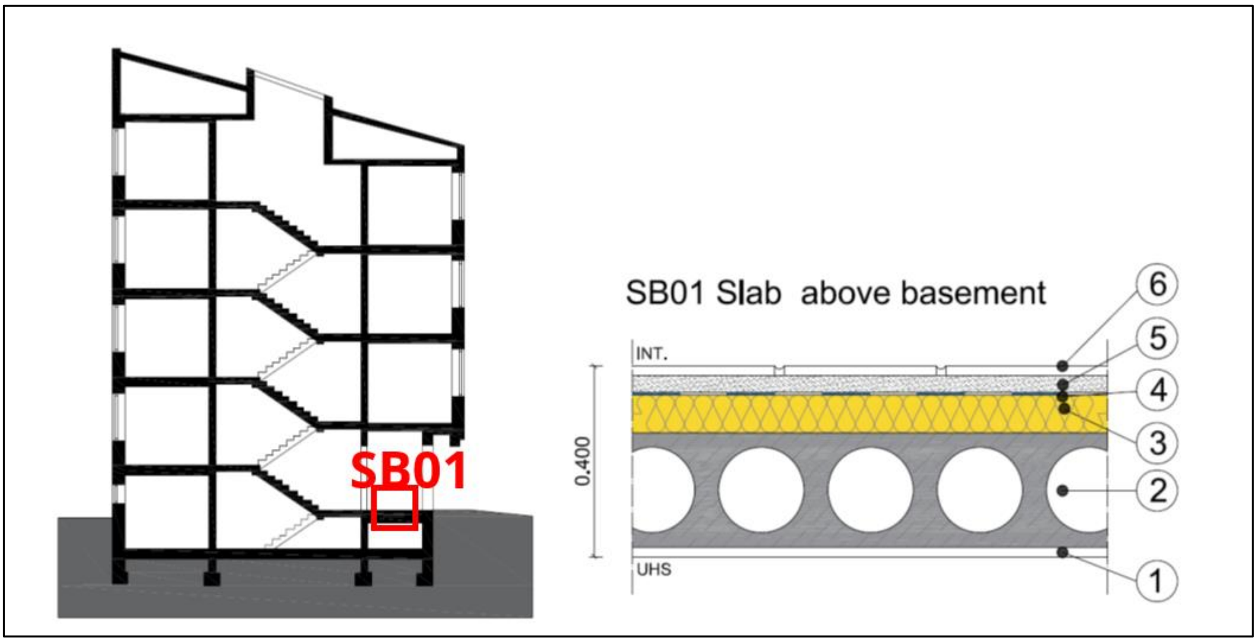


Fig. 1-6: Slab above basement section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Hollow–core slab	24	1,7	0,88	1560
Expanded Polystyrene EPS	8	0,04	1,46	100
Bitumen membrane	0,3	0,18	1,6	-
Cement screed	4	1,6	0,84	1800
Tiles	1,5	-	-	-

Table 1-3: Slab above basement materials

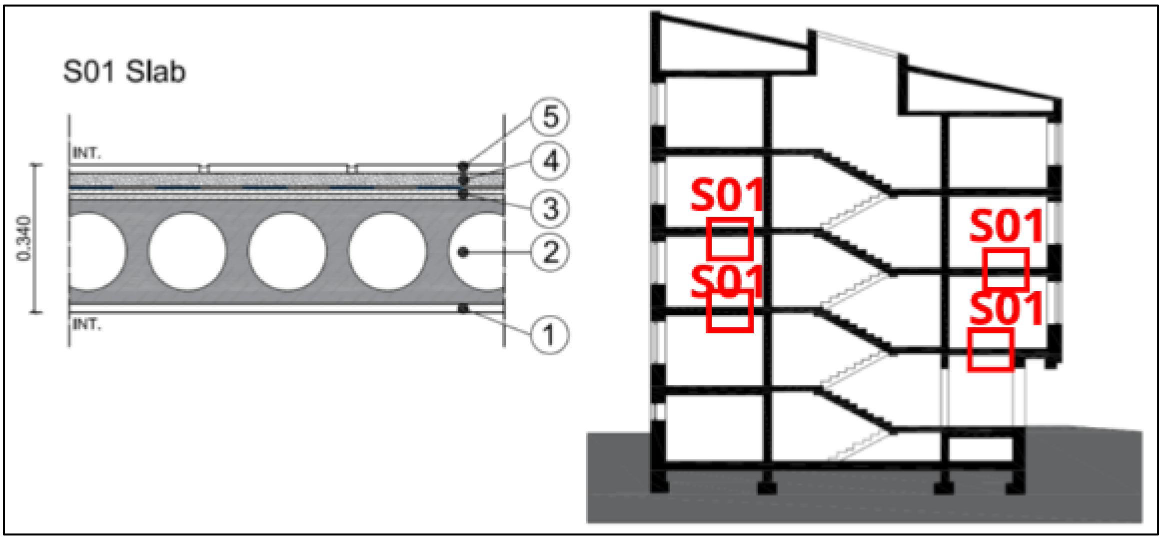


Fig. 1-7: Slab section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Hollow–core slab	24	1,7	0,88	1560
Double layer of fiberboard	2,5	0,44	1,7	600
Bitumen membrane	0,3	0,18	1,6	-
Cement screed	4	1,6	0,84	1800
Tiles	1,5	-	-	-

Table 1-4: Slab section materials

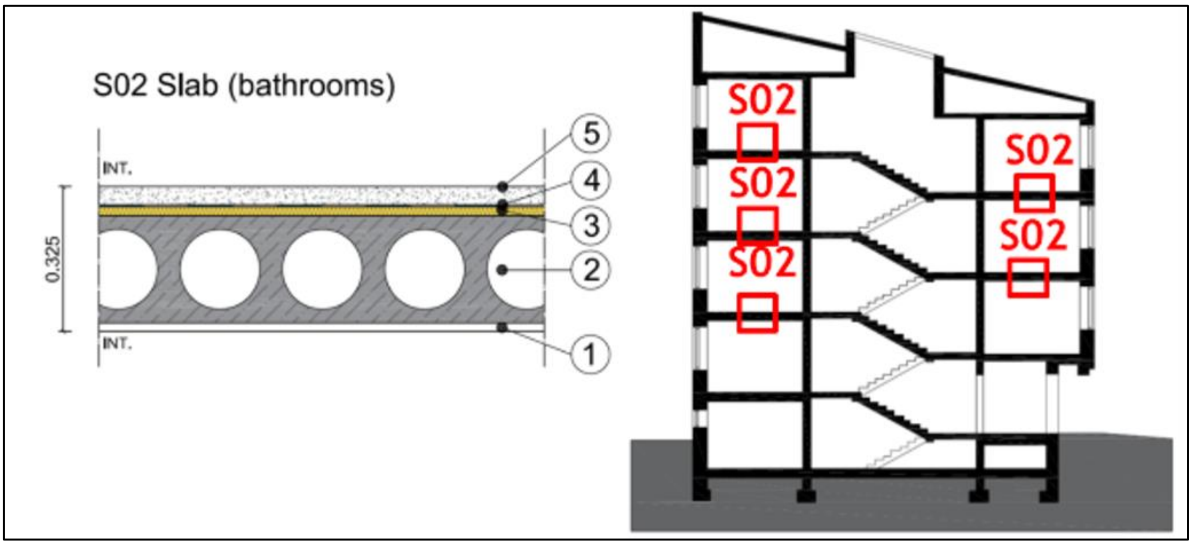


Fig. 1-8: Bathroom slab section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Hollow–core slab	24	1,7	0,88	1560
Expanded Polystyrene EPS	2,5	0,44	1,7	600
Bitumen membrane	0,3	0,18	1,6	-
Terazzo Tiles	4	-	-	-

Table 1-5: Bathroom slab section materials

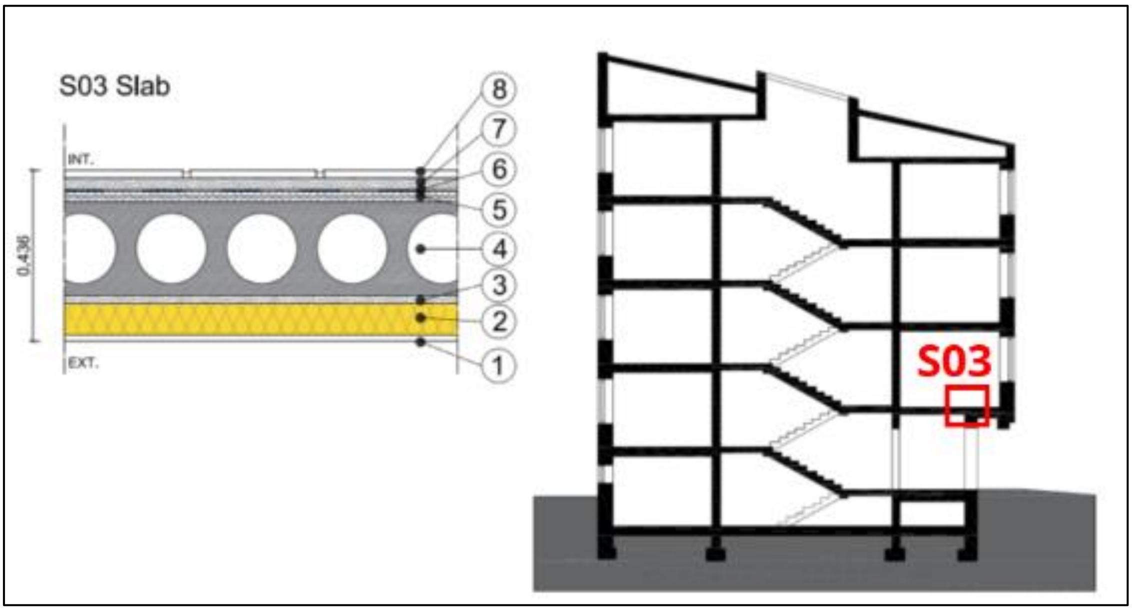


Fig. 1-9: Slab Section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Expanded Polystyrene EPS	10	0,44	1,7	600
Adhesive layer	2	1,4	0,84	2200
Hollow – core slab	24	1,7	0,88	1560
Double layer of fiberboard	2,5	0,44	1,7	600
Bitumen membrane	0.3	0,18	1,6	-
Cement screed	4	1,6	0,84	1800
Tiles	1,5	-	-	-

Table 1-6: Slab materials

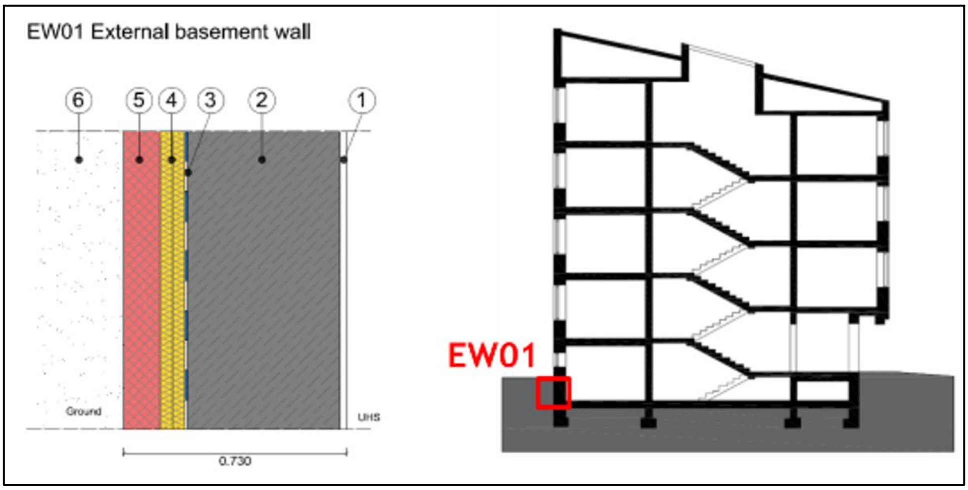


Fig. 1-10: External Basement wall section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m^3)
Plaster	2	1,4	0,84	2200
Concrete	24	1,7	0,84	1800
Bitumen membrane	0,3	0,18	1,6	-
Double layer of EPS	8	0,44	1,7	600
Brick	12	0,36	1,0	1100

Table 1-7: External basement wall section materials

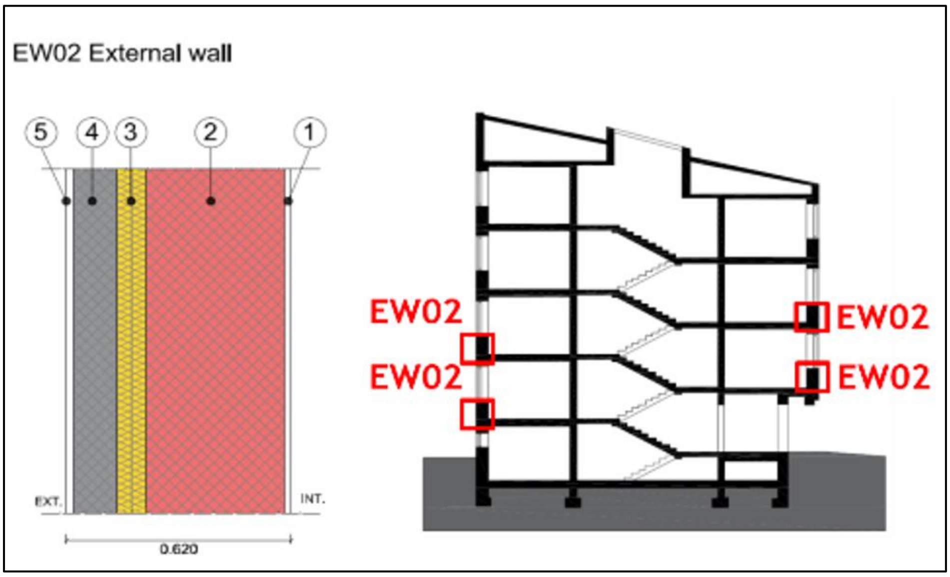


Fig. 1-11: External wall section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m3)
Plaster	2	1,4	0,84	2200
Brick	24	0,36	1,0	1100
Double layer of EPS	8	0,44	1,7	600
Autoclaved aerated concrete	12	0,24	1,0	600
Plaster	2	1,4	0,84	2200

Table 1-8: External wall section materials

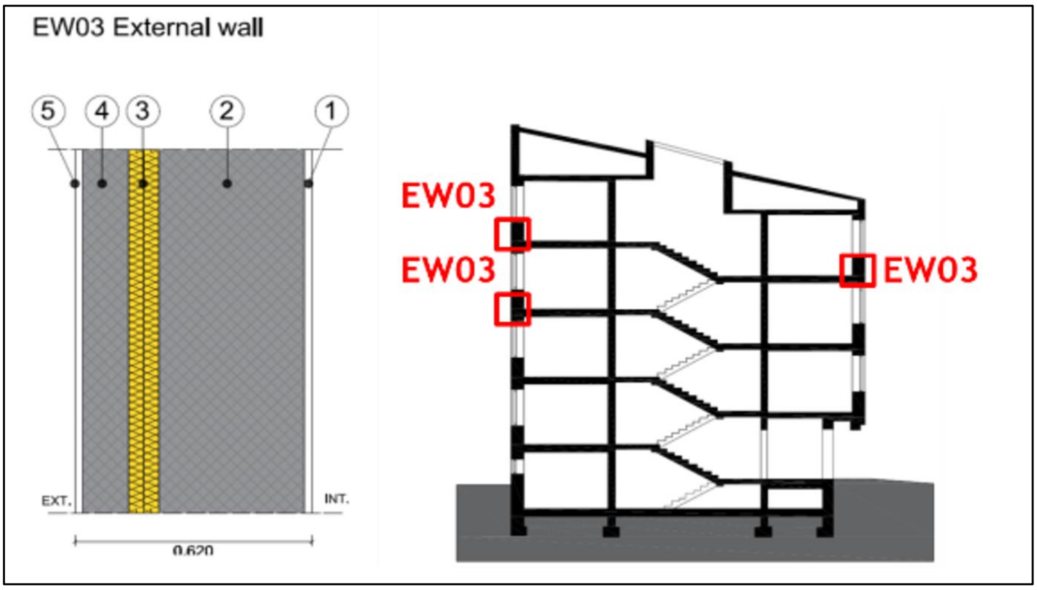


Fig. 1-12: External wall section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Autoclaved aerated concrete	24	0,24	1,0	800
Double layer of EPS	8	0,44	1,7	600
Autoclaved aerated concrete	12	0,24	1,0	800
Plaster	2	1,4	0,84	2200

Table 1-9: External wall section materials

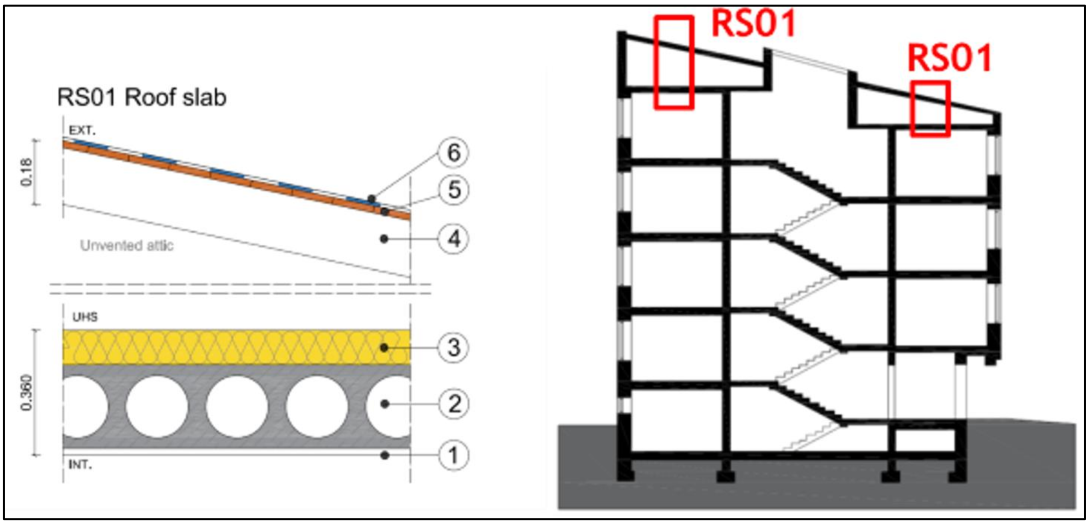


Fig. 1-13: Roof Slab Section

Material	THK (cm)	Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)
Plaster	2	1,4	0,84	2200
Hollow-core slab	24	1,7	0,88	1560
Mineral wool MW	10	0,04	1,03	30
Wooden deck	1,5	0,13	0,85	500
Bitumen membrane	0,3	0,18	1,6	-

Table 1-10: Roof slab section materials

Table 1-11 summarizes the different window types at the Polish pilot building along with their corresponding thermal properties and dimensions. Initially, double-glazing windows with timber frame were installed. In the period between 2000-2010, windows were replaced with PVC double glazing windows with estimated U = 1,5 W/m2K. Only one apartment has kept its old windows.

Fig. 1-14: Currently and previously installed windows

Number of Units	Type	Heat Transfer Coefficient (U)	Visual Light Transmittance	Solar Heat Gain Coefficient
Window types				
52	PVC Window - 1470x1760mm	3.1292 W/(m²·K)	0.81	0.76
58	PVC Window - 855x1150mm	3.1292 W/(m²·K)	0.81	0.76
28	PVC Window - 810x1440mm	3.1292 W/(m²·K)	0.81	0.76
28	PVC Window - 1440x1450mm	3.1292 W/(m²·K)	0.81	0.76
18	Timber frame Window - 750x1150mm	4.5600 W/(m²·K)	0.68	0.49

Table 1-11: Window types of Polish pilot building

1.2.3 Heating, Ventilation and Air Conditioning

Ventilation System

According to the Energy Audit that was performed in 2021, only gravity ventilation is available in the building. This type of ventilation does not use any additional devices or mechanical support. Natural ventilation is based only on the air flow and pressures differential.

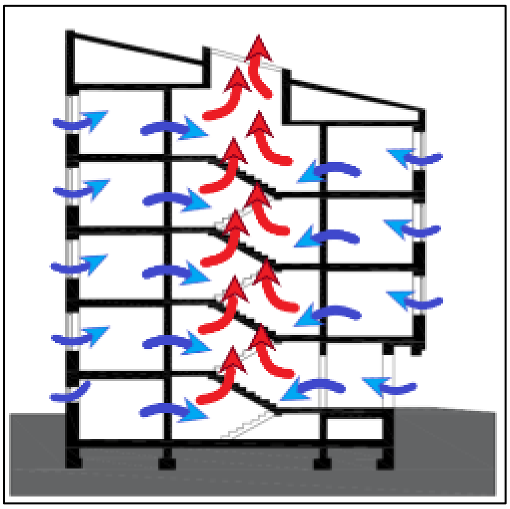


Fig. 1-15: Air flow visualization

Heating system:

Initially, the electric heating system in the building was implemented with electric convector heaters in each apartment and hot water was produced by using electric boilers. In 2017, a central heating system was installed with the following characteristics:

- Central heating room is in the basement with access to the district heating substation (see Fig. 1-16)
- All the radiators were replaced
- Central heating is fuelled by hard coal in the cogeneration process providing both electric and heating power for the building including hot domestic water
- Domestic hot water is prepared in a compact dual-function heating node supplied with heat from the municipal network.

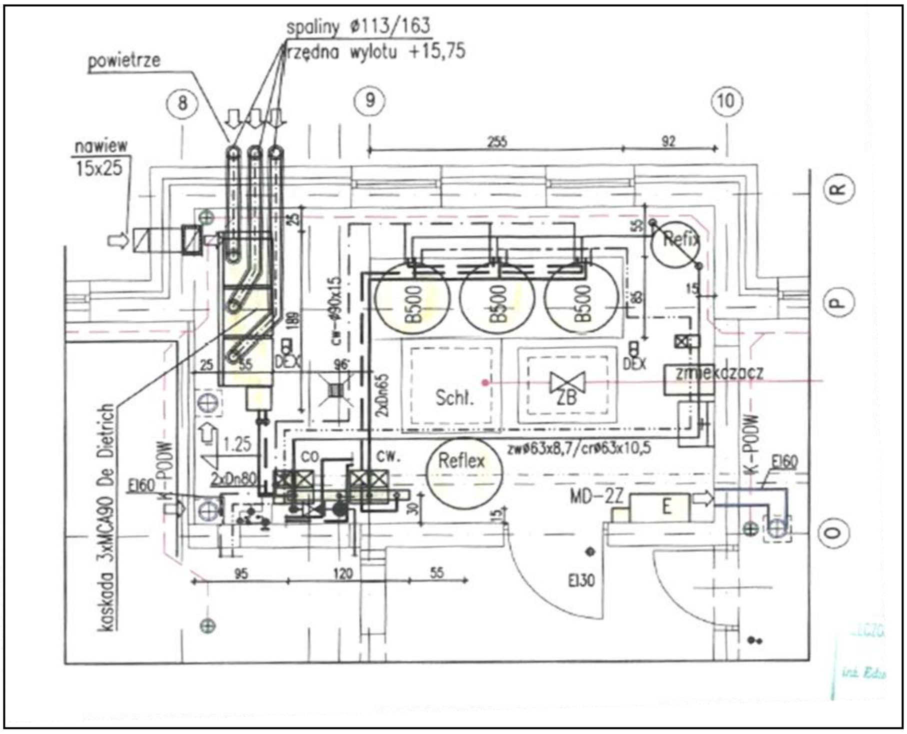


Fig. 1-16: Central heating room (Basement)

1.2.4 Other Energy Usage Equipment and Internal Gains

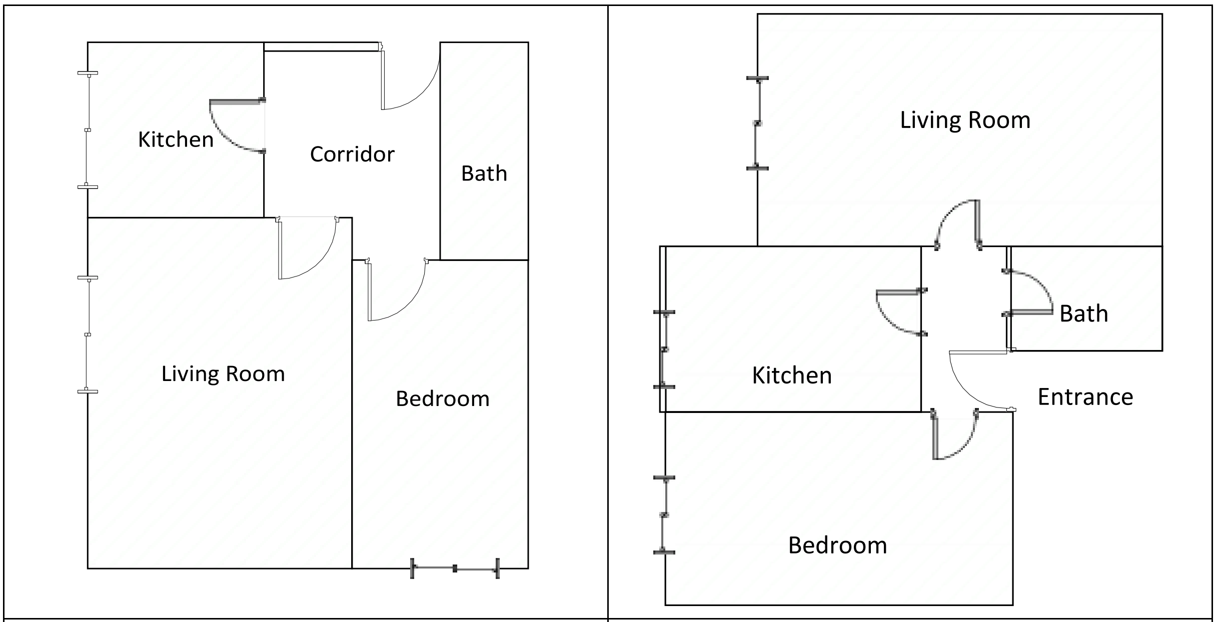
The operating electric equipment as well as people that act as internal thermal sources, is called internal gains. Usually, the internal gains are estimated based on the number of people being inside a building room/space and the operational schedules for equipment in the same room.

Table 1-12 lists the number of residents in the selected flats of the Polish pilot building that will be used in the context of internal gains calculations.

Flats	Number of people living in the flat
7	2
15	2
24	5
29	2
32	2
58	2
63	5
64	2

Table 1-12: Number of occupants in the selected flats

It should be noted that two types of apartments (A and B) are identified at the Polish pilot building (as also shown in Fig. 1-17). The area of each different room is approximately the same for the 4 selected flats of each type, and hence, the occupant density of each room can be calculated as shown in the compact form of Table 1-13 and Table 1-14, respectively.



(a) Flat type: A | (b) Flat type: B

Fig. 1-17: Flat configurations

Room/Space	Flat:	7	15	58	63
	#Occupants:	2	4	2	5
	Room Surface (m^2)	Density (Occupants/m^2)			
Living Room	17	0,12	0,24	0,12	0,29
Kitchen	5,85	0,34	0,68	0,34	0,85
Bathroom	4,18	0,48	0,96	0,48	1,20
Bedroom 1	11,7	0,17	0,26	0,17	0,43
Corridor	8,61	0,23	0,46	0,23	0,58

Table 1-13: Occupant density for Flat type A

Room/Space	Flat:	24	29	32	64
	#Occupants:	5	2	2	2
	Room Surface (m^2)	Density (Occupants/m^2)			
Living Room	15,57	0,32	0,13	0,13	0,13
Kitchen	5,02	1	0,4	0,4	0,4
Bathroom	4,69	1,06	0,46	0,46	0,46
Bedroom 1	7,54	0,66	0,27	0,27	0,27
Corridor	3,78	1,32	0,53	0,53	0,53

Table 1-14: Occupant density data for Flat type B

Regarding the internal gains generated by the artificial lighting and electrical equipment, extensive tables have been provided by the pilot partner (see ANNEX I). Herein, Table 1-15 provides a short indicative excerpt of this data targeting only apartments of Level 1.

Internal Gains							
				Artificial Lighting data		Electric Equipment data	
				Specified Lighting Load / Lighting bulbs/tubes Power	Specified Lighting Load per area/Artificial lighting gains (W/m2)	Specified Power Load/Electric Equipment Power	Specified Power Load per area/Electric Equipment gains (W/m2)
Staircase 1							
Level 1							
	Apartment nr.1						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.2						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²

Table 1-15: Artificial Lighting data and Electric Equipment data (Level 1). (*For the full table with internal gains see ANNEX I).*

1.2.5 Climate data

The Warsaw region experiences an oceanic climate with influence of humid continental atmospheric conditions. Winters are cloudy, cold, and sometimes snowy, with lowest average temperatures of -1,8°C in January. Spring and autumn are periods of mild temperature and in summer average daily temperatures can reach 19,2°C in July (Fig. 1-18). During summer the temperature can reach above 30°C. Yearly rainfall is 529 mm on average, which makes Warsaw the sixth driest major city in Europe.

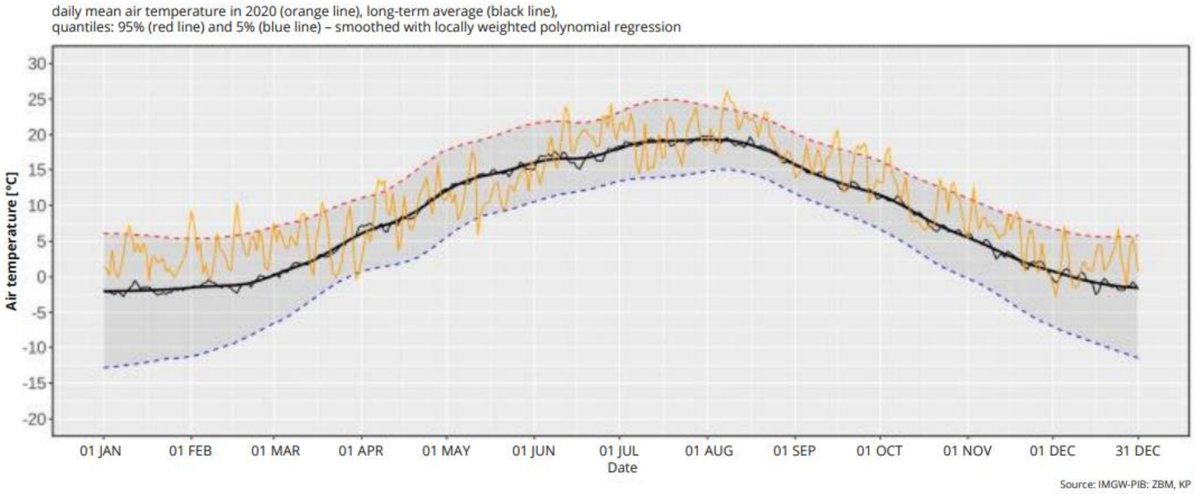


Fig. 1-18: Variability of the daily mean temperature in 2020 in reference to long-term characteristics 1981-2010 (source: Institute of Meteorology and Water Management - National Research Institute "Climate in Poland 2020")

1.2.6 BIMERR Input Data Requirements

BIMERR tools attempt to coordinate the different phases of the renovation process, so their operation is highly based on specific data sets that need to be generated in each renovation project.

The starting point of the overall BIMERR renovation process is the Scan-to-BIM tool and its sub-components. Its purpose is to generate the enhanced Building Information Modeling (BIM) model of the renovation building. Firstly, Scan-to-BIM [3] requires point clouds of the building, which are delivered by laser scanners (Section 1.2.6.1), in order to produce the BIM-model of the building structure. Secondly, it uses simple images (1.2.6.1) to detect non-structural objects such as radiators and to automatically add them to the BIM-model.

The final BIM model and the associated Industry Foundation Classes (IFC) files (Section 1.2.6.2) are to be used by the ARIBFA tool [4] that aims to enrich the BIM model on site and the RenoDSS tool [5] that is responsible for evaluating the impact of different renovation options to the building performance.

Targeting occupants' behavior, the BIMERR PRUBS [6] module attempts to model it in a standardized XML schema. For this reason, IoT data streams, such as room air temperature, humidity, electric power metering data, etc. are required (Section 1.2.6.4) along with data regarding weather conditions (Section 1.2.6.5).

BIMERR performance evaluation regarding energy efficiency along with cost and time demands of the renovation project is addressed by the BEP modelling component [7] and the Renovation Process Simulation tool [8]. Both require a set of baseline data (Section s 1.2.6.6 and 1.2.6.7) in order to provide efficiency metrics.

Finally, the specific renovation measures (Section 1.2.6.8) that are selected in the context of each pilot building and will be implemented during the construction phase are also considered as input requirement to the BIMERR ecosystem. The Renovation Process Simulation tool will model the entire process and the derived workflow will be imported and executed in the context of Adaptive workflow management & automation tool [9].

1.2.6.1 3D Scanning

The work that was done to create the 3D Point Cloud for the Polish pilot building is described in this Section. The following comments are based on interviews with the subcontractor responsible for the scanning of the building:

- Data acquisition was made in a couple of different dates due to apartment access issues. The first survey for the exterior part was done on July 3rd, 2020. The interior parts of the building were surveyed on the following dates: July 24th, October 6th, and 15th. Unfortunately, there was no roof access.
- The exact positioning of the laser scanner was established based on the experience of the laser scanning team of the sub-contractor.
    - A minimal number of positions was required to scan all faces from all elements (especially the main features such as structural elements).
    - For the exteriors, approximately 7 to 10 meters was established between every position.
    - In places where tall trees blocked the view, the distance between scans was reduced to 3-5 meters.
- For the internal scanning the windows were opened to connect interior scans with the external.
- Due to easier point cloud access and generation of the panorama 360, the offline access to the point cloud was generated. To better visualise point cloud, 360º panoramic pictures were taken and aligned. In addition, offline access to the point cloud was generated.
- A resolution of 1 point/5mm was established to have a manageable Point cloud (smaller file size).
- For this kind of residential tower, there are generally 2 main difficulties:
    - The access to flats (or common areas), as it can be difficult to manage to get the approval and to find a date that fits all residents. Not all residents agreed to give an access to their apartments.
    - Due to limited roof access, it was not possible to scan roof from the ground level.

Fig. 1-19 shows a sample image of the output of the Lidar 3D scan used during the scanning process and Fig. 1-20 shows all scanning positions during the scanning campaign.

Fig. 1-19: Lidar 3D Scan output

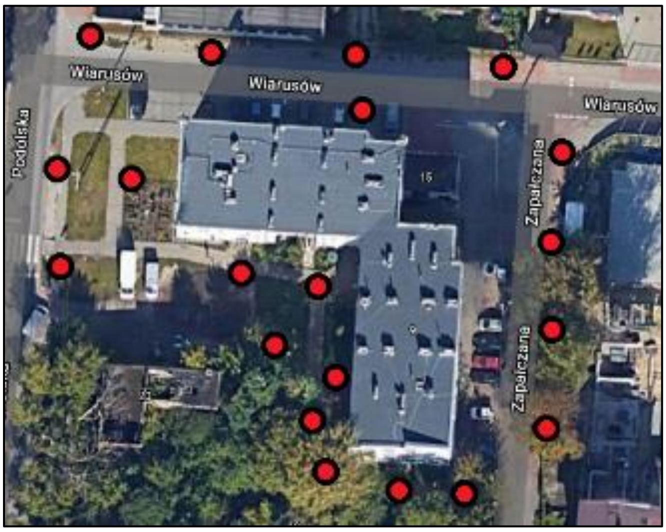


Fig. 1-20: Lidar scanner locations

The two pictures below (Fig. 1-21 and Fig. 1-22) show examples of the 360º pictures that have been extracted from the interior and exterior scanning.

Fig. 1-21: Building Interior lidar scan

Fig. 1-22: Building exterior lidar scan

Finally, the image below shows a screenshot of the 3D point cloud that was created.

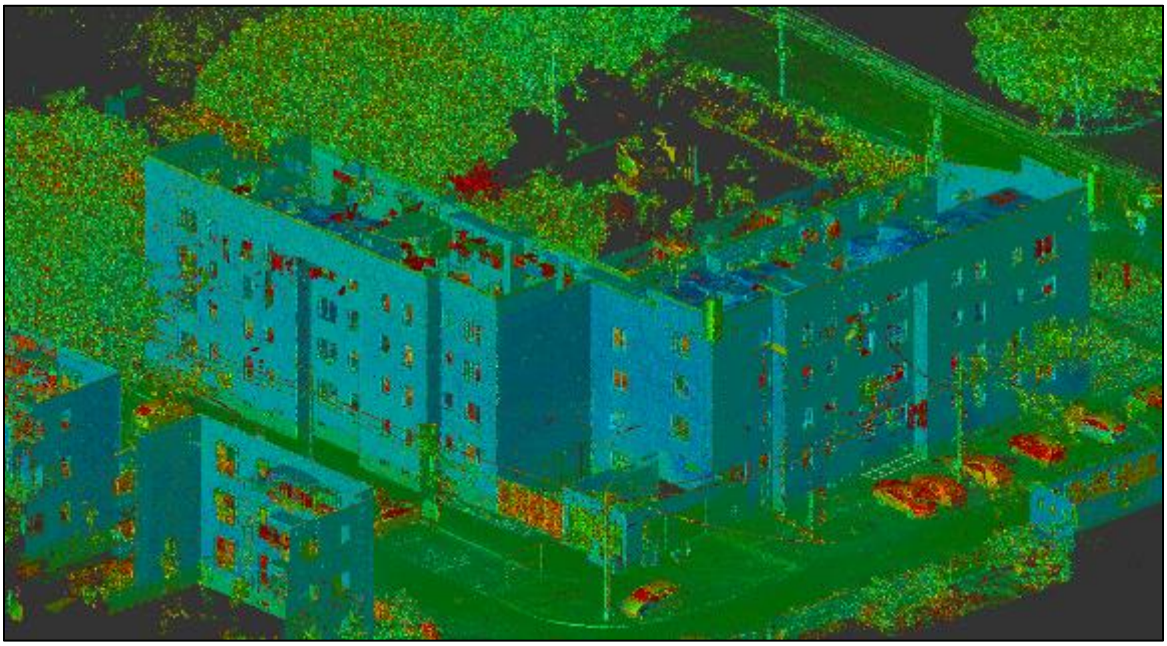


Fig. 1-23: 3D point cloud as a result of the laser scanning campaign

1.2.6.2 BIM model in Revit and IFC exportation

Fig. 1-24 and Fig. 1-25 present visual results of the model delivered by the BIM modeler working with the Polish partner at the beginning of 2021. The model creation has been made according to the BIM design guidelines that can be found in [10] and [11].

The BIM model creation is still ongoing, the final model including all constructive features should be delivered at the end of 2021 beginning of 2022.

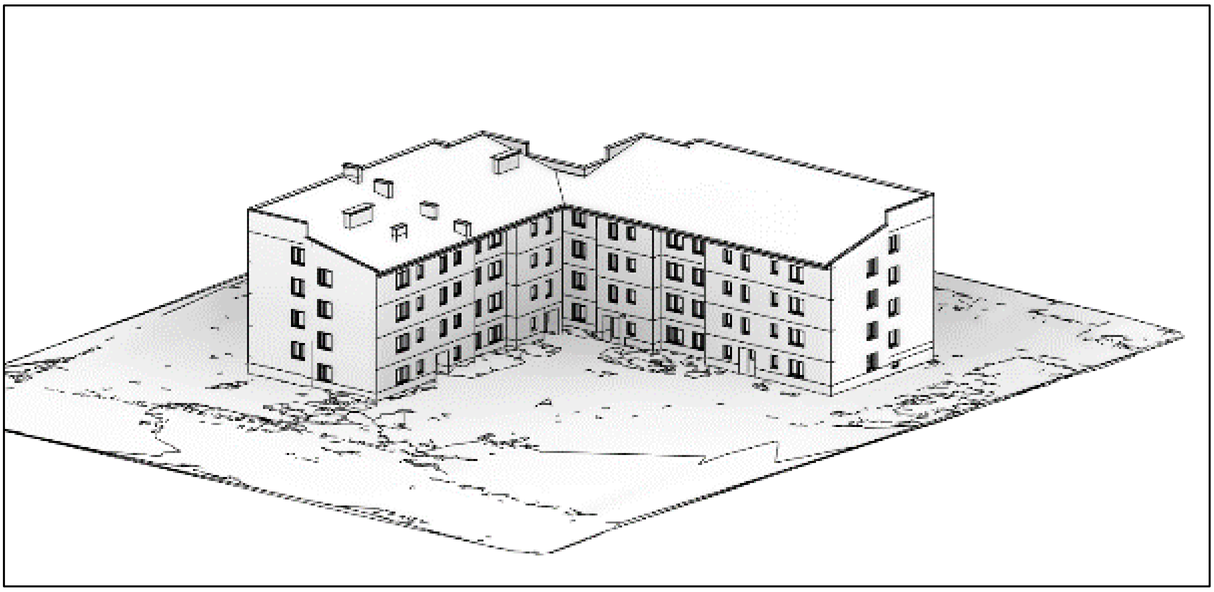


Fig. 1-24: Draft of Revit BIM Model

Fig. 1-25: Revit visualization of the created BIM Model

1.2.6.3 Visual Data – Images

Pictures taken with a phone camera were processed by the BIMERR MEP Object Detection Web Service, which identified and classified HVAC entities (radiators in the case of the Polish building) installed in the different spaces. Fig. 1-26 illustrates the kitchen of the zone "flat nr. 15" and the kitchen of flat nr. 52, where radiators have been identified (highlighted in green).

(a)

(b)

Fig. 1-26: MEP components (radiators) identified, (a) in the kitchen of "flat nr. 15" and (b) in kitchen of flat nr. 52

1.2.6.4 Sensing, Monitoring and Metering Data

All the information included in this section was produced in WP5 in the context of T5.4, and hence, the final WSN design for the Polish pilot building along with further details can be found in [6].

As mentioned earlier in this deliverable, the Polish pilot site consists of two independent buildings:

a. **Building A** with 4 floors and 8 apartments per floor (totally 32 apartments).

b. **Building B** with 4 floors and 8 apartments per floor (totally 32 apartments).

For the needs of the BIMERR Project the following apartments, with reference to Fig. 1-27, are used for the deployment of the WSN: **Apartments Nr. 7, 15, 24, 29, 32, 58, 63, 64**.

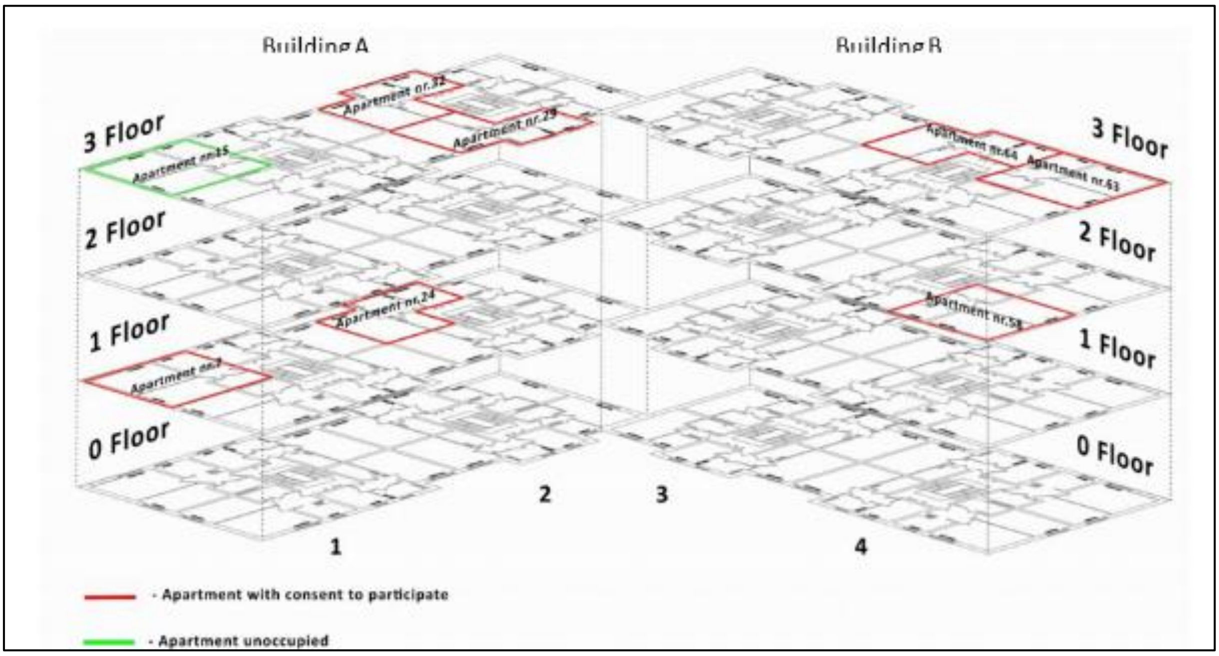
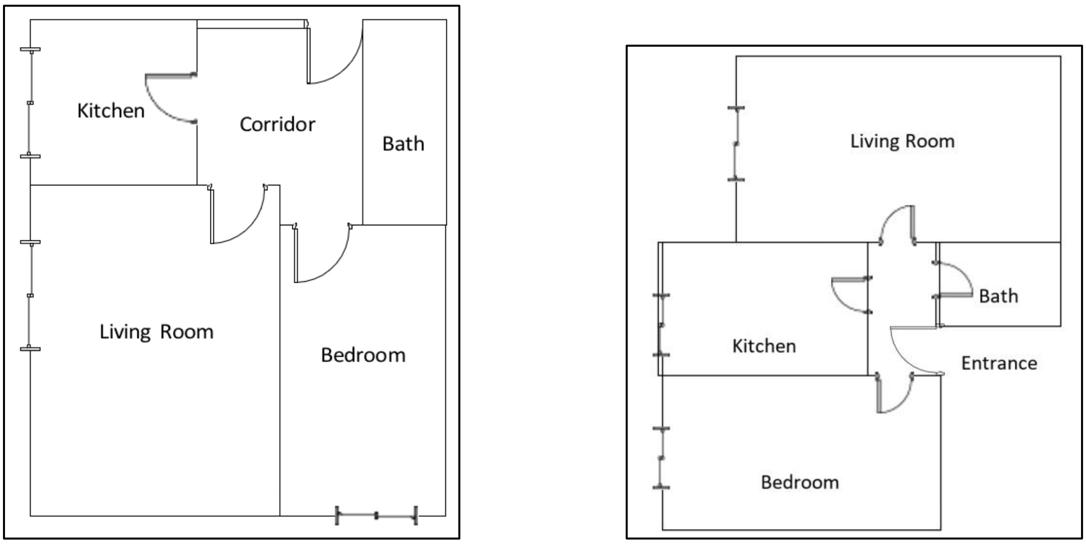


Fig. 1-27: Visualization of flat configuration

The proposed apartments can be grouped into two configurations:

- **Configuration 1** [Apartments Nr. 7, 15, 58, 63]. This configuration includes the following spaces: a Bedroom, a Living Room, a Kitchen, and a Bathroom. All rooms "communicate" via a Corridor, as depicted in Fig. 1-28a.
- **Configuration 2** [Apartments Nr. 24, 29, 32, 64]. This configuration includes the following spaces: a Bedroom, a Living Room, a Kitchen, and a Bathroom. All rooms "communicate" via a Corridor, as depicted in Fig. 1-28b.



(a) (b)

Fig. 1-28: (a) Polish pilot site apartment configuration 1, (b) Polish pilot site apartment configuration 2

Fig. 1-29 shows some photos of the actual sensors installed in the flats of the Polish pilot building in August 2021.

(a) (b) (c)

(d) (e)

Fig. 1-29: Pictures of installed sensors: (a) Fibaro Home Center Lite (b) Humidity and CO2 sensor (c) Motion Sensor (d) Window Sensor (e) Radiator Sensor

1.2.6.5 Weather Data Files – Typical Meteorological Year and Actual Data

For the energy performance assessment, RenoDSS-BEP embeds the EnergyPlus simulation engine. Following a granular approach that uses small timesteps (usually fifteen-minutes), comparable to the time scale of time-varying physical effects that are being modelled, EnergyPlus requires weather data of hourly temporal resolution for a year to simulate the weather conditions impact on building's thermal behavior.

A brief literature review has revealed two main categories of weather data that are used in the BEP simulation's domain: (1) Annual Meteorological Year (AMY) that includes measured data from a local weather station and for a specific year; (2) Typical Meteorological Year (and more precisely TMY3) that contains representative climate data for a given location. In the latter, data for the last fifteen years, measured from weather stations located in airports, is collected, and statistically process to conclude to typical/representative weather data for each hour of the year. Although TMY3 files cannot capture local microclimate effects, research studies in the BEPs domain have concluded that AMYs are not appropriate for annual BEP simulation combined with a decision-making process (evaluation on candidate renovation measures), since a single AMY might not be representative of a longer period. It is also worth mentioning that EnergyPlus (BEPs engine) performs some microclimate effects calculations based on the building's location (provided by the IFC file).

To conduct the BEP simulations for both pilot sites, RenoDSS access the EnergyPlus TMYs repository. Via GET Requests, RenoDSS retrieves a JSON that contains links to EnergyPlus Weather (EPW) weather data files for different locations, expressed by their longitude and latitudes. These coordinates are parsed and contrasted with the IFC files' longitude and latitude to find the weather data file that is nearest to the location of the Polish building.

Furthermore, actual measured data from weather stations are required to facilitate the occupant behavior models training (PRUBS) and the baseline BEP model calibration (see Section 1.2.6.7). Actual weather data is received from external weather APIs. For both pilot sites, the Dark Sky APIs have been used. Two different accounts have been created to receive a Dark Sky secret key. With the secret key, latitude, longitude, time and unit as request parameters, API responses are JSON-format objects that includes values for outdoor temperature, humidity, cloud coverage, etc.

1.2.6.6 COST - TIME BASELINE DATA REQUIREMENTS

The Cost and Time Baseline data is provided by the industrial partner in an Excel file with predefined structure. The proposed Excel structure is based on the structure of the PWMA Olive microservices that will read it and combine the baseline values to calculate the dependent KPIs. A KPI specific model has been created, reflecting the structure of the KPI dependencies, and defining the calculation formula that combines the different metrics. The KPI model has reference also to the microservices that extract the baseline values from Excel. In this way the KPI dashboard has all the information required to (a) retrieve metrics, (b) calculate KPIs and (c) visualize them in a dashboard.

More details on the KPIs models and microservices are available in the D6.3 [12] and D6.5 [8].

Since not all Cost and Time KPIs have baseline scenarios due to the innovation introduced with the BIMERR tools, the following table provides the KPIs for which the baseline values will be provided by the industrial partner.

KPI ID	Metric Name	Description	Value	Notes
CT01	T_{BIM}^{BL}	Time required for creating the BIM model (only geometry).	56h	BIM model based on 2D documentation.
CT02	$T_{Comp2BIM}^{BL}$	Time required to add an additional energy component to an already created BIM model.	16h	Creating and placing all radiators and thermostats.
CT02	N_{Comp}	Number of energy components that are installed in the pilot building.	479	

CT41	$T^{BL}_{AsIsEnrg}$	Time required to complete the as-is energy model with traditional approaches.	2 weeks	
CT42	$T^{BL}_{RenScenEv}$	Time required to perform evaluation of different renovation scenarios under the conventional approach.	2 weeks	
CT04	T_{DLY}	Estimation of the delay caused to construction works when a planning error occurs.	1 week	Potential issues like: delay in material delivery, subcontractor unavailability
CT04	N_{ISS}	Estimation of the number of issues that may occur.	3	
CT35	T_{IEA}	Estimation on time required for a successful information exchange action between stakeholders during phases prior to construction.	4h	Highly depend on type of document and version of it. Usually, final version has to be send via post with acceptance protocol to be signed. In parallel same document can be send by e mail for preview, but it's not official way of delivering. All preparation for sending official document can take several hours.
CT08	CT08	Number of adjustments to the project schedule after its first finalization.	3	
CT34	T^{BL}_{resc}	Estimation on the time required to reschedule works after the detection of an issue.	4h	
CT40	$T^{BL}_{WF,i}$	An estimation of the time required for a specific renovation measure (i^{th} workflow) to be executed.		Rough estimates regarding base renovation scenario assumed in public tender. May subject to change, when design changed
		1) Construction site preparation	1 week	
		2) Scaffolding	1 week	
		3) External wall Surface preparation	2 weeks	
		4) External wall Laying new insolation	2 weeks	
		5) External wall Plastering, facade finishing	3 weeks	
		6) Roof insolation	2 weeks	
		7) Basement windows replacement	1 week	
		8) Basement wall preparation +insolation	3 weeks	
		9) Minor finishing works	1 week	
		10) Construction site clearing, dismantling scaffolding etc.	2 weeks	
CT20	CT20	Number of different renovation measures that will be implemented (i.e., windows installation, façade insulation, etc.) as executable workflows.	7	

CT25	$T^{BL}_{as-built}$	Duration of preparing the as-built documentation.	7 days	
CT38	T^{BL}_{UpdBIM}	Time required to update the BIM model with a modification under the baseline scenario.	8h	
CT26	CT26	How many times an identified issue on site led to a modification to the BIM model.	5	
CT27	T^{BL}_{SchAct}	Estimation on the time required for scheduling activities on site under the baseline scenario.	0,5h	
CT27	N_{SchAct}	Construction phase duration.	90	
ICT01	$T^{BL}_{RenProject}$	Estimation on the time required for renovation project.	18 weeks	
ICT02	$C^{BL}_{RenProject}$	Estimation on the cost required for renovation project.	700 000 PLN	Very rough estimate - highly depends on renovation measures and subject to significant changes due to currently observed rapid price changes of constructions materials.

Table 1-16: Cost and Time KPIs - Baseline Metrics

1.2.6.7 ENERGY BASELINE DATA REQUIREMENTS

The building's energy baseline corresponds to the as-is energy performance (demands, consumption, usage profiles, etc.) of the building before being renovated. To estimate it, RenoDSS conducts the baseline simulation for each project (pilot site), using as input (1) the as-is BIM model in IFC format, (2) the occupant behaviour data in obXML format, and (3) weather data in EPW format (see Sections 1.2.6.4 and 1.2.6.5 that explain how IoT data for obXML file generation and weather data, respectively, is collected).

The as-is BIM model is the IFC file that is exported from Revit (see Section 1.2.6.2). It captures all the thermal properties of the as-is buildings materials, internal gains, infiltration rates and energy characteristics of the Heating, Ventilation and Air Conditioning (HVAC) system. Despite the significant effort of the BIM modelers to collect as accurate information as possible, assumptions for some properties values are often made, resulting to the known gap between measured and simulated energy performance.

To reduce this gap, the option D of the International Performance Measurement and Verification Protocol (IPMVP) is used, where some actual (measured) performance data is required to calibrate the baseline energy performance simulation model. Actual performance data includes building electric power consumption measurements, retrieved from the IoT devices installed at each apartment, and district heating readouts.

1.2.6.8 RENOVATION MEASURES THAT WILL BE IMPLEMENTED

The energy audit that was carried out to prepare the necessary documents for the tender process indicated six main building elements which qualify for renovation to improve the energy efficiency of the building. The improvements that were recommended in the context of the energy audit are described below.

1. **Insulation of floor slab over drive**

   Total area of floor slab to insulate is 10,19 m². It is required to use material of thermal conductivity of min. lambda = 0.031 W/mK, and thickness of 0,2 m to achieve a thermal transmittance (U-factor) of 0.141 W/(m²K).

2. **Insulation of roof slab**

   Total area of floor slab to insulate is 754,92 m². It is required to use material of thermal conductivity of min. lambda = 0.039 W/mK, and thickness of 0,2 m to achieve a thermal transmittance (U-factor) of 0.141 W/(m²K).

3. **Insulation of external wall in basements**

   Total area of wall to insulate is 149,51 m². It is required to use material of thermal conductivity of min. lambda = 0.035 W/mK, and thickness of 0,1 m to achieve a thermal transmittance (U-factor) of 0.289 W/(m²K).

4. **Insulation of external wall**

   Total area of wall to insulate is 1744,87 m². It is required to use material of thermal conductivity of min. lambda = 0.039 W/mK, and thickness of 0,12 m to achieve a thermal transmittance (U-factor) of 0.187 W/(m²K).

5. **Replacement of wooden windows in basements**

   Total area windows to be replaced is 8,65 m². It is indicated to use PVC type of window, no specific parameters mentioned.

6. **Insulation of base wall in the ground**

   Total area of wall to insulate is 273,86 m². It is required to use material of thermal conductivity of min. lambda = 0.035 W/mK, and thickness of 0,1 m to achieve a thermal transmittance (U-factor) of 0.288 W/(m²K).

These renovation measures are listed in the official document that led to the public tender process, as the base scenario for renovation. Due to the ”Design and Build” basis of the announcement, it may be subject to change, if the main contractor proposes other renovation measures that will lead to better parameters of energy efficiency.

1.2.7 Estimation of a high-level Gantt

Since the public tender for the renovation of the Polish pilot site is still on ongoing, an estimated high level Gantt chart based on the Energy Audit of the Polish pilot building is provided here in (see Fig. 1-30).

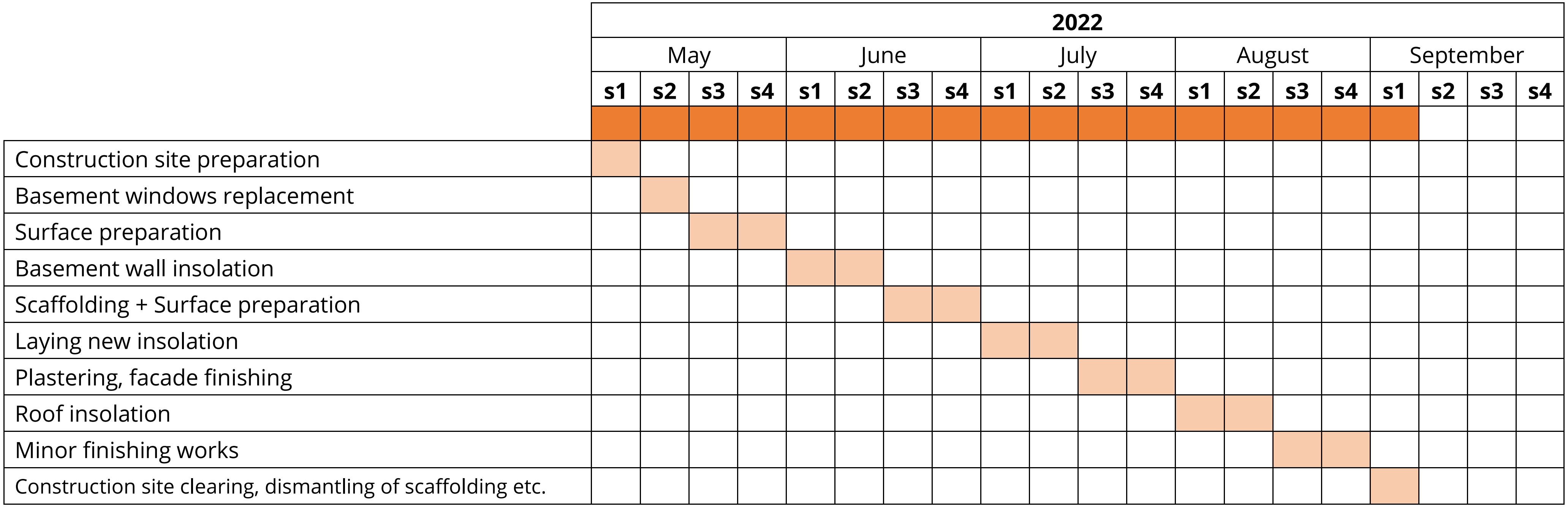


Fig. 1-30: Estimated high level Gantt chart of works in the Polish pilot building.

1.3 SPANISH BUILDING

The Spanish pilot building is located in the North of Spain, in the Basque country, in the surroundings of the industrial city of Bilbao. The exact address of the building is: Larrakoetxe Kalea, 1, 48004 Bilbao, Bizkaia, cadastral reference U1244160Q. The elevation of the area above the sea level is 119 m, while the longitude and latitude are -2.8986368 and 43.2607832 respectively.

Fig. 1-31 and Fig. 1-32 depict the area where the building is located.

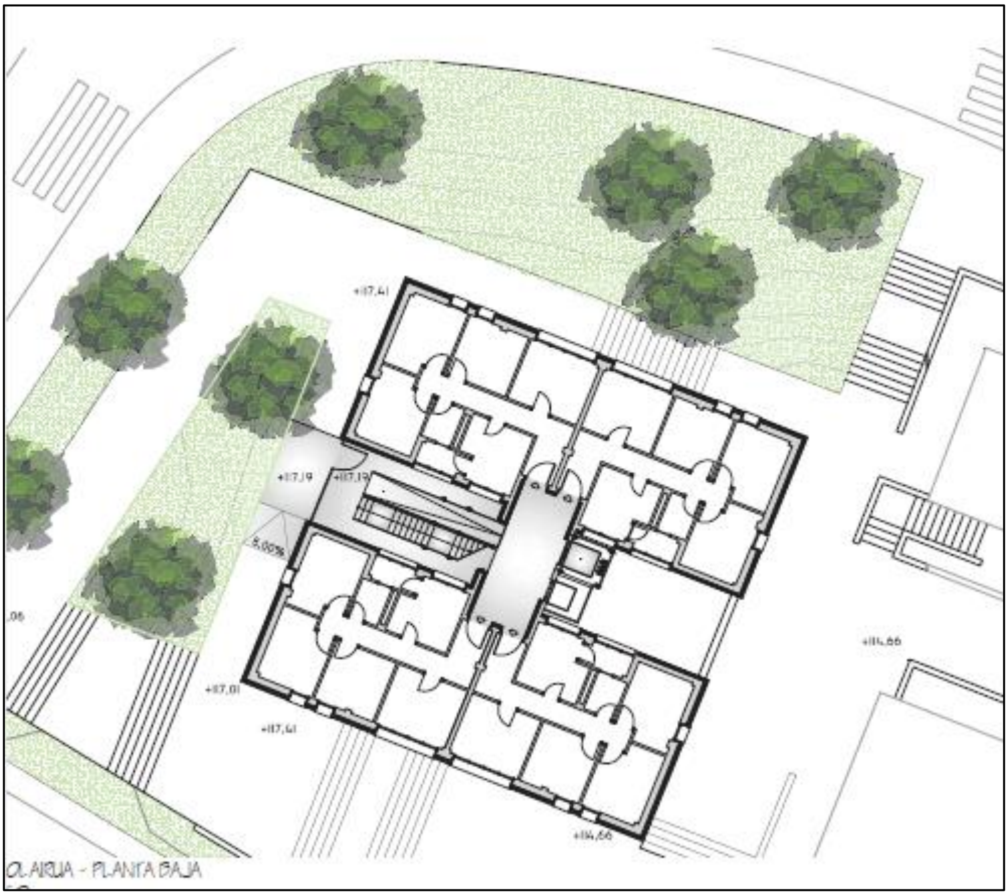


Fig. 1-31: Layout of the pilot site in Spain (Basque country in northern Spain)

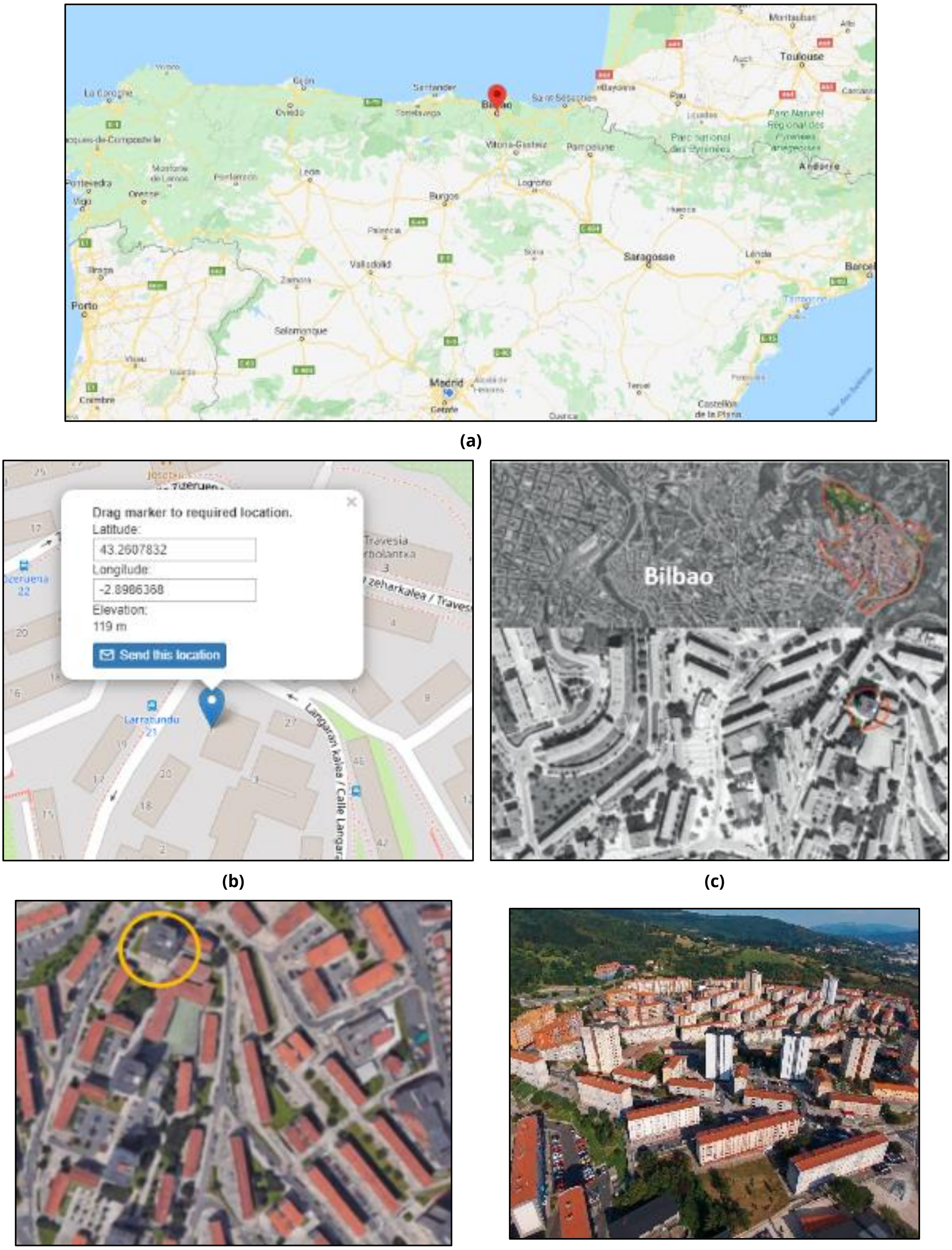


Fig. 1-32: Location of the pilot site in Spain (Basque country in northern Spain)

The building was built in 1960 in the framework of a global urbanistic ensemble and it is 15 storeys high. On the ground floor there are 2 homes and 2 commercial premises, and in each of the remaining 14 floors, there are 4 flats (all very similar, each flat has a surface of approximately 59 m^2, see top view in Fig. 1-31) per floor. So, in total, there are 58 apartments (social housing) and 2 commercial premises. The building is owned by a social housing administration, which rents the flats, but there are also some residents who owns their apartments (approximately 30%).

Several views of the building are shown in Fig. 1-33 to Fig. 1-36.

(a) **(b)** **(c)** **(d)** **(f)**

Fig. 1-33: Spanish pilot building – Exterior views

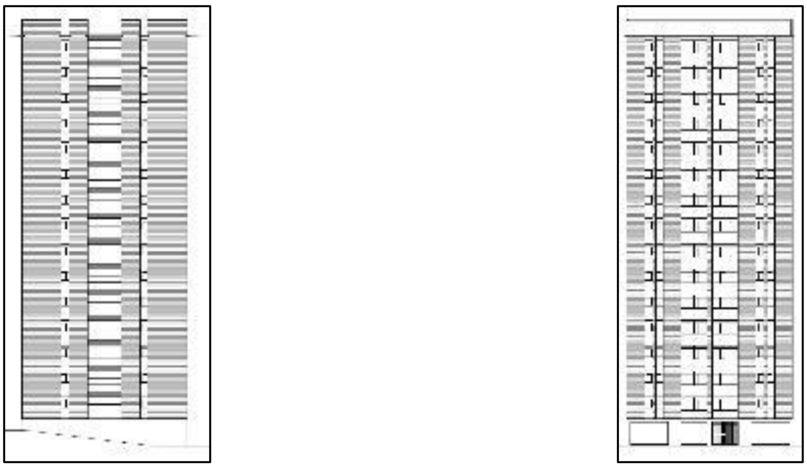
Fig. 1-34: Spanish pilot building – Exterior views (roof)

Fig. 1-35: Spanish pilot building – Interior views

Fig. 1-36: Spanish pilot building – Interior views (window)

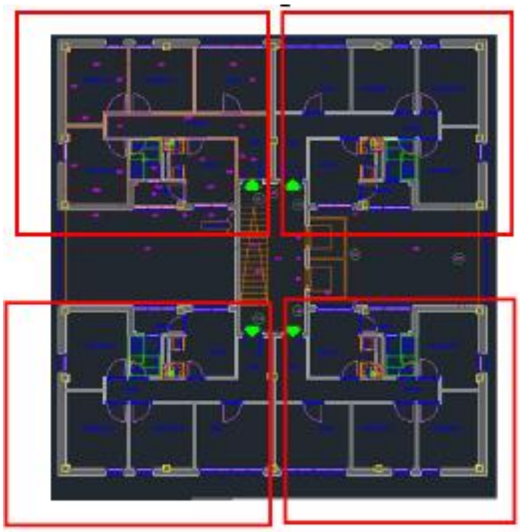
1.3.1 Building Geometry

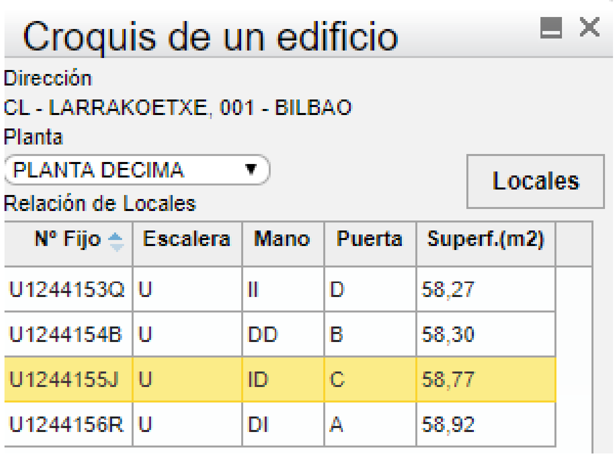
In this section, all the relevant information about the building geometry is summarized, and visually illustrated with in Fig. 1-37 - Fig. 1-41.



(a) **(b)**

Fig. 1-37: (a) The façade seen from S-E or N-W. (b) The façade seen from N-E or S-W.





Croquis de un edificio

Dirección

CL - LARRAKOETXE, 001 - BILBAO

Planta

PLANTA DECIMA

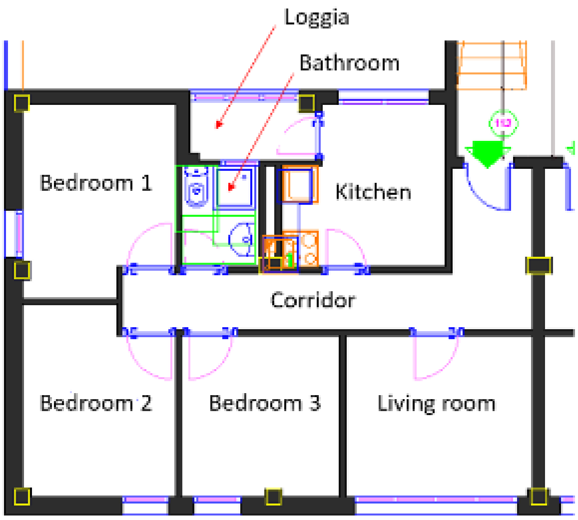
Locales

Relación de Locales

Nº Fijo	Escalera	Mano	Puerta	Superf.(m2)
U1244153Q	U	II	D	58,27
U1244154B	U	DD	B	58,30
U1244155J	U	ID	C	58,77
U1244156R	U	DI	A	58,92

(a) (b)

Fig. 1-38: (a) Top view of one floor. (b) Screenshot from the cadastral registration with corresponding surfaces of 4 flats located in a same floor.



	Surface (m2)
Living room	8.24
Kitchen	6.62
Bathroom	2.15
Bedroom 1	7.56
Bedroom 2	7.54
Bedromm 3	7.02
Corridor	8.61
Loggia	1.99

(a) (b)

Fig. 1-39: (a) Top view of one typical flat. (b) Usual surface of each room in a typical flat.

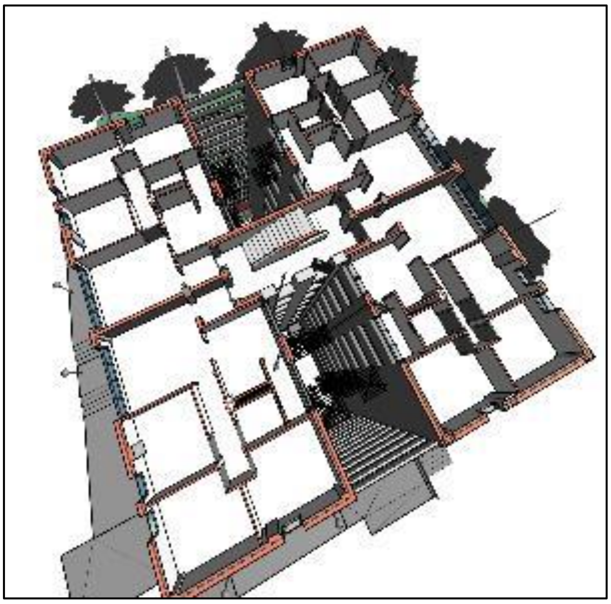


Fig. 1-40: Top-view of an entire floor (extracted from BIM model).

The picture below shows the building orientation, the flat distribution, and its nomenclature.

Fig. 1-41: Building orientation

1.3.2 Building Materials and Construction

First, we describe some important features about the current state of the building envelope. The current thermal envelope of the building can be considered as in poor condition and insufficient to ensure comfort in the flats. As it can be seen in the picture below, the overall envelope is composed by the 4 main façades, and by 2 "U-shapes" parts that "enters" inside the main block.

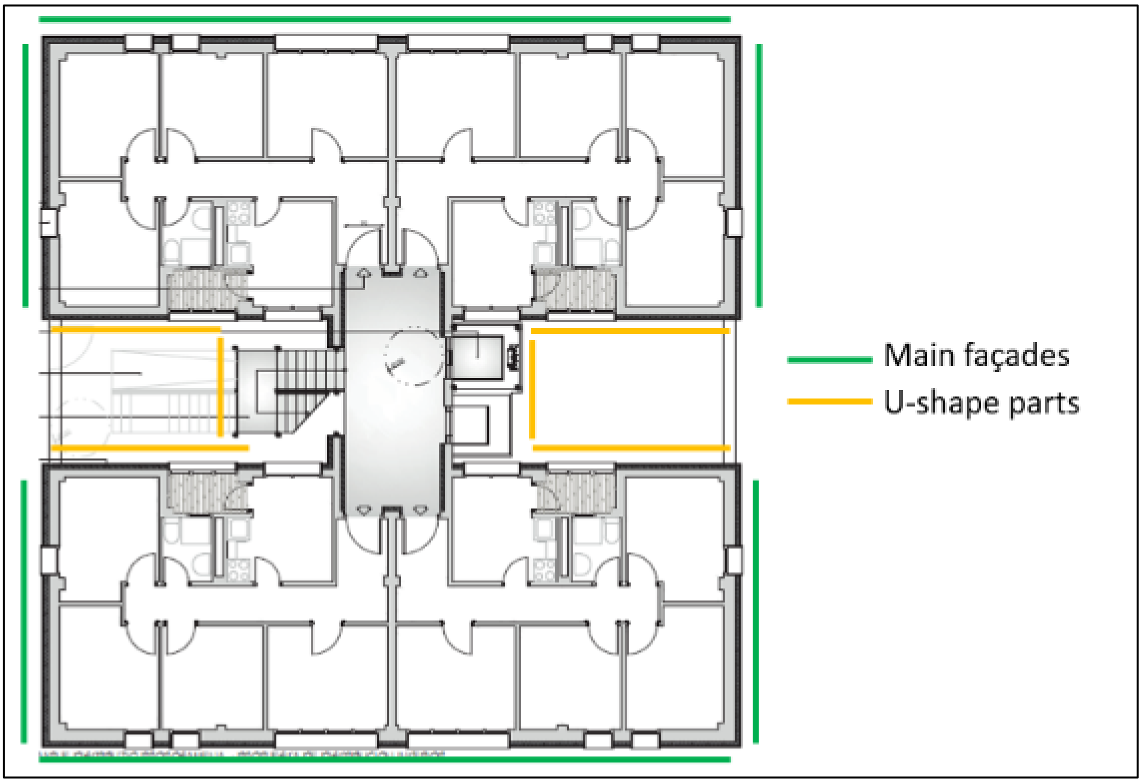


Fig. 1-42: Façade elements in the Spanish pilot site

In all these façade elements, the current façade is made of simple layers, such as depicted in the picture below (Fig. 1-43).

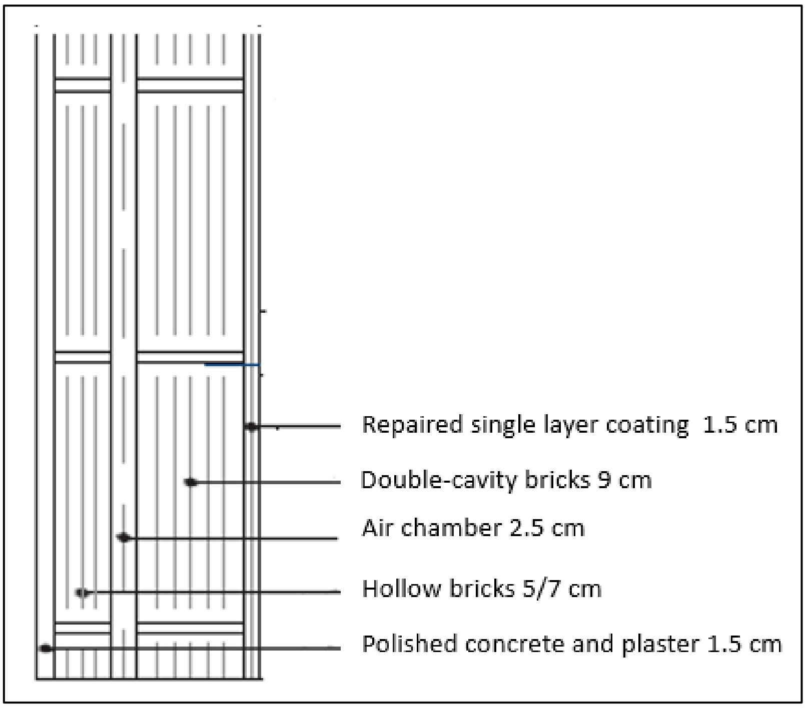


Fig. 1-43: Current façade layer elements

On the roof, the thermal insulation is quite poor as well, the composition of the layers is described in Fig. 1-44:

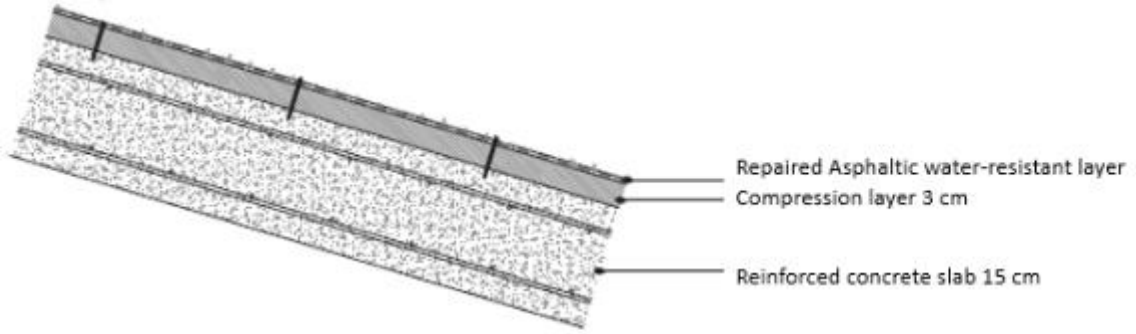


Fig. 1-44: Current roof layer elements

A detailed table with the properties of construction materials is provided in the next Table 1-17.

Main Façade	Thickness (e)	Conductivity (k)	Specific Heat	Density	Thermal Absorptance	Solar Absorptance	Roughness
FAC_Enfoscado 26 cm PPAL EXIS	m	W/mK	J/kgK	kg/m³			
Painting layer	0,000	0,200	1423	1180	0,95	1,00	1,00
Cement mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Hollow brick Partition	0,115	0,660	840	1550	0,95	1,00	1,00
Cement Mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Air chamber (without ventilation)	0,025	0,148					
Hollow brick Partition	0,060	0,430	840	1550	0,95	1,00	1,00
Plaster coating	0,020	0,570	960	1120	0,90	1,00	1,00
TOTAL	**26,0 cm**						
Façades in the patios	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Enfoscado 26 cm PATIOS EXIS	m	W/mK	J/kgK	kg/m³			
Painting layer	0,000	0,200	1423	1180	0,95	1,00	1,00
Cement Mortar1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Hollow brick Partition	0,115	0,660	840	1550	0,95	1,00	1,00
Cement mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Air chamber (without ventilation)	0,025	0,148					
Hollow brick Partition	0,060	0,430	840	1550	0,95	1,00	1,00
Plaster coating	0,020	0,570	960	1120	0,90	1,00	1,00
TOTAL	**26,0 cm**						
Façade in the staircase area	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Enfoscado 26 cm ESC EXIS	m	W/mK	J/kgK	kg/m³			
Painting layer	0,000	0,200	1423	1180	0,95	1,00	1,00
Coment Mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Hollow brick Partition	0,115	0,660	840	1550	0,95	1,00	1,00
Cement Mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Air chamber (without ventilation)	0,025	0,148					
Hollow brick Partition	0,060	0,430	840	1550	0,95	1,00	1,00

Plaster coating	0,020	0,570	960	1120	0,90	1,00	1,00
TOTAL	**26,0 cm**						
Façade in the lift area	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Hormigon ASC 40 cm EXIS	m	W/mK	J/kgK	kg/m³			
Reinforced concrete	0,4	2,30	657,00	2300	0,95	1,00	1,00
TOTAL	**40,0 cm**						
Façade in ground floor	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Hormigon+Ceramica 32 cm	m	W/mK	J/kgK	kg/m³			
Ceramic piece	0,020	1,000	1700	850	0,90	1,00	1,00
Reinforced concrete	0,300	2,300	657,00	2300	0,95	1,00	1,00
TOTAL	**32,0 cm**						
PETOS CUBIERTA	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Enfoscado 26 cm PETOS	m	W/mK	J/kgK	kg/m³			
Painting layer	0,000	0,200	1423	1180	0,95	1,00	1,00
Cement mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Hollow brick Partition	0,115	0,660	840	1550	0,95	1,00	1,00
Cement mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Air chamber (without ventilation)	0,025	0,148					
Hollow brick Partition	0,060	0,430	840	1550	0,95	1,00	1,00
Cement mortar 1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
TOTAL	**26,0 cm**						
BARRACKS ON THE ROOF	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
FAC_Ladrillo+Enfoscado 13,5 cm (casetones)	m	(W/mK)	(J/kgK)	(kg/m3)			
Cement mortar1800<d<2000	0,020	0,550	920	1650	0,95	1,00	1,00
Hollow brick Partition	0,115	0,660	840	1550	0,95	1,00	1,00
TOTAL	**13,5 cm**						
ROOF	**Thickness (e)**	**Conductivity (k)**	**Specific Heat**	**Density**	**Thermal Absorptance**	**Solar Absorptance**	**Roughness**
CUB_Hormigon+TelaAsfaltica 6 cm	m	(W/mK)	(J/kgK)	(kg/m3)			
Asphalt sheet	0,000	0,331	2092	920	0,95	1,00	1,00
Reinforced concrete (Compressive layer)	0,050	2,300	657	2300	0,95	1,00	1,00
TOTAL	**5,0 cm**						

Table 1-17: Construction materials properties

Glazing materials differ between all the flats as the windows have been changed by the owners along the years. Many flats have simple aluminum windows which do not meet the basic requirements to avoid thermal bridge or ensure waterproofness or resistance to the wind. Fig. 1-45 shows a picture of the external glazing materials of the building.

Fig. 1-45: Picture of the building's façade (External glazing)

Fig. 1-46 and Table 1-18 summarize the different window types present at the Spanish pilot building along with their corresponding thermal properties.

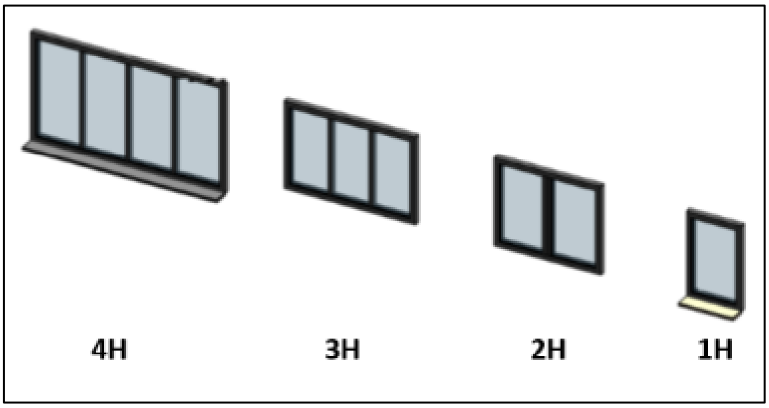


Fig. 1-46: Different window types.

Units	Type	Heat Transfer Coefficient (U)	Visual Light Transmittance	Solar Heat Gain Coefficient
VEN_1H				
21	Alum RPT 2 vidrios - 75x115cm	2.8400 W/(m²·K)	0.68	0.49
6	Alum SRPT - 75x115cm	5.5600 W/(m²·K)	0.9	0.86
63	Mad 2 vidrios - 75x115cm	2.5300 W/(m²·K)	0.68	0.49
9	Mad vidrio simple - 75x115cm	4.5300 W/(m²·K)	0.9	0.86

75	PVC 2 vidrios - 75x115cm	2.5600 W/(m²·K)	0.68	0.49
VEN_1H (caseton cubierta)				
2	45 x 45 cm	3.6886 W/(m²·K)	0.9	0.78
1	70 x 70 cm	3.6886 W/(m²·K)	0.9	0.78
VEN_1H Interior				
58	50x60cm			
VEN_2H				
9	Alum RPT 2 vidrios - 145x120cm	2.8000 W/(m²·K)	0.68	0.49
3	Alum SRPT - 145x120cm	5.5400 W/(m²·K)	0.9	0.86
19	Mad 2 vidrios - 145x120cm	2.5800 W/(m²·K)	0.68	0.49
6	Mad vidrio simple - 145x120cm	4.8100 W/(m²·K)	0.9	0.86
19	PVC 2 vidrios - 145x120cm	2.6000 W/(m²·K)	0.68	0.49
VEN_2H Barrotes (Lonja)				
2	195x75cm	6.7018 W/(m²·K)	0.08	0.19
VEN_3H				
8	Alum RPT 2 vidrios - 180x120cm	2.7900 W/(m²·K)	0.68	0.49
4	Alum SRPT - 180x120cm	5.5400 W/(m²·K)	0.9	0.86
17	Mad 2 vidrios - 180x120cm	2.5900 W/(m²·K)	0.68	0.49
9	Mad vidrio simple - 180x120cm	2.6100 W/(m²·K)	0.68	0.49
20	PVC 2 vidrios - 180x120cm	2.6100 W/(m²·K)	0.68	0.49
VEN_4H				
7	Alum RPT 2 vidrios - 265x150cm	2.7700 W/(m²·K)	0.68	0.49
23	Mad 2 vidrios - 265x150cm	2.6200 W/(m²·K)	0.68	0.49
3	Mad vidrio simple - 265x150cm	5.0200 W/(m²·K)	0.9	0.86
1	PVC 2 vidrios - 265x130cm (2+2)	2.6300 W/(m²·K)	0.68	0.49
1	PVC 2 vidrios - 265x140cm (4+3)	2.6300 W/(m²·K)	0.68	0.49
21	PVC 2 vidrios - 265x150cm	2.6300 W/(m²·K)	0.68	0.49
1	PVC 2 vidrios - 265x150cm (2+2)	2.6300 W/(m²·K)	0.68	0.49
1	PVC 2 vidrios - 265x150cm (4+2)	2.6300 W/(m²·K)	0.68	0.49

Table 1-18: Thermal properties of glazing materials

1.3.3 Heating, Ventilation and Air Conditioning

As mentioned earlier in this deliverable, the building is owned by a social housing administration, which rents the flats, but there are also some residents who own their flats. Furthermore, some renovation measures have been undertaken, some of them for the whole building, but others only for privately-owned apartments. For that reason, the heating and cooling system is not centralized, neither uniform. From the 58 apartments in the building, 42% are heated via gas boiler, and 58% with electric systems.

In the five flats that will be monitored, the heating is done via electric radiators, there are no cooling systems.

1.3.4 Domestic Hot Water

As mentioned in the previous section, the hot domestic water system is not uniform. The following table shows the actual equipment in each flat (before the renovation), with some technical information about capacities. During the building renovation, there will be a change of heaters in

26 flats (mainly the flats that belong to the social housing committee Viviendas de Bilbao, privately owned flats should not expect changes). The new heaters will be gas-based condensation boiler from the brand Hemann (MICRAPLUS CONDENS 25kW).

The five flats that are being monitored in the framework of the BIMERR project are shown in the table below with red (6C, 8D, 11B, 12D, 13A). In these flats, an electric boiler is used for the hot water supply. It should be noted that there is a heater change in two of them (underlined in the table).

Flat Orientation	A	B	C	D
Floor				
1		Vaillant "Turbo tc exclusive" estanca (96,6%)	Electrical heater 30L	
2	Hermann "micraplus Condens 25kW" condensación (97%)	Electrical heater 100L	Butane water heater	Electrical heater 100L 1.5kW
3	Electrical heater 80L	No heater	Fagor "lowNOX comfort" condensación (96,2%)	Electrical heater 30L 1.5kW
4	Electrical heater 30L 1.6 kW	Electrical heater 30L 1.5 kW	Saunier-Duval "Thema F23E 23,30kW" condensación (94,5%)	Butane water heater
5	Electrical heater 80L 1.5 kW	Butane water heater	Electrical heater 25L	Butane water heater
6	Electrical heater 80L 2 kW	Butane water heater (88,5%)	**Electrical heater 75L**	Electrical heater 50L 1.5kW
7	Roca "RS 20/20F 23,25kW" (91%)	N/A	Electrical heater	Roca "sin modelo" condensación (98,8%)
8	Electrical heater	Butane water heater	Caldera conesación (94,8%)	**Electrical heater 50L 1.6kW**
9	Caldera estanca (91,70%)	Electrical heater	Electrical heater 30L	No heater
10	Electrical heater	Butane water heater	Electrical heater	Electrical heater
11	Electrical heater 30L 1.2 kW	**Electrical heater**	Electrical heater 100L 1.5kW	No heater
12	Electrical heater 30L	Electrical heater 50L	Electrical heater 150L	**Electrical heater**
13	**Electrical heater 100L**	Electrical heater 30L	No heater	Roca "RS 20/20F 23,25kW" (68,2%)
14	Ariston "Class One 24kW" (97,7%)	Ariston "Class One 24kW" (97,7%)	N/A	Electrical heater
15	Electrical heater	No heater	Electrical heater 50L 1.5 kW	Hermann "micraplus Condens 25kW" condensación (97%)

Table 1-19: Current situation regarding equipment installed in each flat

1.3.5 *Other Energy Usage Equipment and Internal Gains*

Table 1-20 gives the total number of people living in the preselected flats where metering data will be available in the context of BIMERR (see also Section 1.3.7.4).

Flats	Number of people living in the flat
6B	1
8D	2
11B	5
12D	4
13A	2

Table 1-20: Number of occupants in the preselected flats

It should be noted that all flats in the Spanish pilot building are almost identical, so the area of each different room (see also Fig. 1-47) is approximately the same among the 5 preselected flats. Therefore, the occupant density of each room can be calculated in the compact form of Table 1-21.

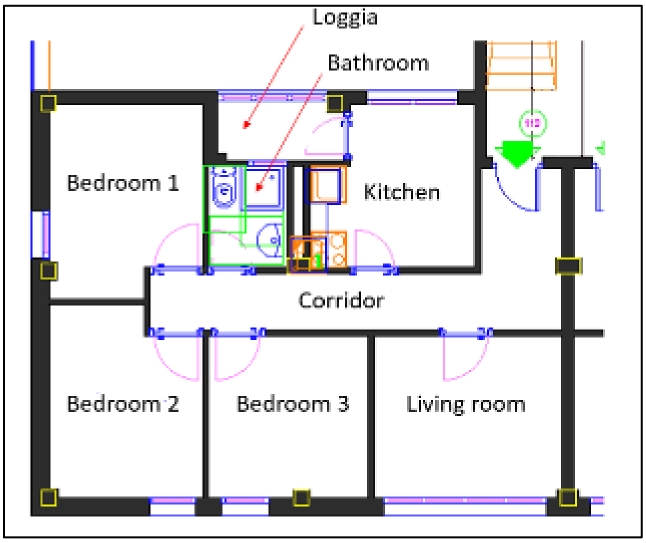


Fig. 1-47: Flat configuration

Room/Space	Flat:	6B	8D	11B	12D	13A
	#occupants:	1	2	5	4	2
	Room Surface (m^2)	Density (Occupants/m^2)				
Living Room	8,24	0,12	0,24	0,61	0,49	0,24
Kitchen	6,62	0,15	0,3	0,76	0,6	0,3
Bathroom	2,15	0,47	0,93	2,33	1,86	0,93
Bedroom 1	7,56	0,13	0,26	0,66	0,53	0,26
Bedroom 2	7,54	0,13	0,27	0,66	0,53	0,27
Bedroom 3	7,02	0,14	0,28	0,71	0,57	0,28
Corridor	8,61	0,12	0,23	0,58	0,46	0,23

Table 1-21: Occupant's density data

Regarding the internal gains generated by the artificial lighting and electrical equipment extensive tables have been provided by the Spanish pilot partner for all the flats in [13].

1.3.6 Climate data

Its proximity to the Bay of Biscay gives Bilbao an oceanic climate, with precipitation occurring throughout the year and without a well-defined dry summer. Precipitation is abundant, and given the latitude and atmospheric dynamics, rainy days represent 45% and cloudy days 40% of the annual total. The rainiest season is between October and April, November being the wettest. Snow is not frequent in Bilbao, although it is possible to see snow on the top of the surrounding mountains. Sleet is more frequent, about 10 days per year, mainly in the winter months. Bilbao is near to the subtropical boundary of all the Atlantic coastal cities in the country with an August daily mean of 20.9 °C (69.6 °F). There is also a drying trend in summer with only around 50 millimeters (2.0 in) of rainfall in July – but not dry enough to be considered Mediterranean.

The proximity of the ocean also means that the two best defined seasons (summer and winter) remain mild, with low intensity thermal oscillations. Average maximum temperatures vary between 25 and 26 °C (77.0 and 78.8 °F) in the summer months, while the average minimum in winter is between 6 and 7 °C (42.8 and 44.6 °F).

As Fig. 1-48 shows, extreme record observations in Bilbao are 42.0 °C (107.6 °F) maximum (on 26 July 1947) and −8.6 °C (16.5 °F) minimum (on 3 February 1963). The maximum precipitation in a day was 225.6 mm (9 in) on 26 August 1983 when severe flooding was caused by the Nervión river.

Climate data for Bilbao airport: 1981–2010 normals, 1947-2020 extremes [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	23.4 (74.1)	26.8 (80.2)	29.8 (85.6)	33.1 (91.6)	36.0 (96.8)	41.2 (106.2)	42.0 (107.6)	41.9 (107.4)	41.7 (107.1)	33.4 (92.1)	27.6 (81.7)	24.6 (76.3)	42.0 (107.6)
Average high °C (°F)	13.4 (56.1)	14.3 (57.7)	16.5 (61.7)	17.6 (63.7)	20.8 (69.4)	23.4 (74.1)	25.4 (77.7)	26.0 (78.8)	24.6 (76.3)	21.4 (70.5)	16.6 (61.9)	13.9 (57.0)	19.5 (67.1)
Daily mean °C (°F)	9.3 (48.7)	9.7 (49.5)	11.5 (52.7)	12.6 (54.7)	15.7 (60.3)	18.4 (65.1)	20.4 (68.7)	20.9 (69.6)	19.2 (66.6)	16.4 (61.5)	12.4 (54.3)	9.9 (49.8)	14.7 (58.5)
Average low °C (°F)	5.1 (41.2)	5.1 (41.2)	6.4 (43.5)	7.6 (45.7)	10.6 (51.1)	13.4 (56.1)	15.4 (59.7)	15.7 (60.3)	13.8 (56.8)	11.4 (52.5)	8.2 (46.8)	5.9 (42.6)	9.9 (49.8)
Record low °C (°F)	−7.6 (18.3)	−8.6 (16.5)	−5.0 (23.0)	−1.2 (29.8)	0.4 (32.7)	3.6 (38.5)	6.6 (43.9)	6.8 (44.2)	3.8 (38.8)	0.6 (33.1)	−6.2 (20.8)	−7.4 (18.7)	−8.6 (16.5)
Average precipitation mm (inches)	120 (4.7)	86 (3.4)	90 (3.5)	107 (4.2)	78 (3.1)	60 (2.4)	50 (2.0)	76 (3.0)	73 (2.9)	111 (4.4)	147 (5.8)	122 (4.8)	1,134 (44.6)
Average precipitation days	13	11	11	13	11	7	7	8	8	11	13	12	124
Average rainy days	15	14	16	17	17	13	12	12	11	15	15	15	172
Average snowy days	0.7	0.7	0.3	0	0	0	0	0	0	0	0.1	0.3	2.1
Average relative humidity (%)	72	69	68	69	69	70	71	72	71	71	73	72	71
Mean monthly sunshine hours	85	97	132	138	169	180	186	179	160	126	88	78	1,610
Source 1: Agencia Estatal de Meteorología[83]													
Source 2: Agencia Estatal de Meteorología[84]													

Fig. 1-48: Climate data for Bilbao airport

1.3.7 BIMERR Input Data Requirements

This section describes the different data sets and information required by BIMERR tools that were provided from the Spanish pilot building. The data flow among the tools remains the same as with the Polish pilot (see Section 1.2.6)

1.3.7.1 3D Scanning

The work involved in the creation of the 3D Point Cloud for the Larrakoetxe building is described in this section.

The company subcontracted to conduct the scanning was BIM ESCANER[1]. The following comments are based on interviews with BIM ESCANER.

[1] https://www.bimescaner.com/es

1. The data acquisition was done in 2 different days. The first survey for the exterior parts was done on July the 30th, 2020. On September 29th, the scanning of interiors (4 flats: 5A, 6C, 6D, 11B) and of the roof were made.
2. The exact positioning of the laser scanner was established based on the experience of the subcontractor, some of the selection criteria are listed below:
    a. A minimal number of positions to scan all faces from all elements (especially the main features such as structural elements)
    b. For the exteriors, approximately 7 to 10 meters was established between every position.
    c. For the indoor scanning, at least one scan in each space/room was made, so that links can be drawn between each of them.
    d. While this does not relate to the selection of the scanning locations, due to the dense distribution of rooms, a quick scanning was done in each door without colour acquisition to help reduce overall scanning time. The implication of that decision is that no colour and no 360 pictures are available for those scans.
3. For this kind of residential tower, there are generally 2 main difficulties:
    a. The access to flats (or common areas), as it can be difficult to get approval and to find a suitable access date that works with all the residents.
    b. The height of the building: to ensure a reliable scanning of the upper parts, due to the distance, a scanner with suitable performance characteristics is needed.
4. In this specific case, the following difficulties have been noticed:
    a. The flat distribution is especially dense, and the passage from one room to another is quite narrow, so the circulation of the scanner has been more complicated than usual. It was impossible to do a registration using targets, so it was made “cloud to cloud”, which can be less accurate.
    b. The fact that the scanning was done on 2 different days meant that it was not possible to use markers (e.g., on windows) to link exterior scans from the street with indoors scan from the flats. To achieve this, some additional scanning from specific positioning very close to the windows was conducted that enabled linking the 2 point-clouds afterwards (exterior and interior point clouds).
5. Two further comments could be added:
    a. A resolution of 1 point/cm was established to have a manageable point cloud (lower size).
    b. A geo-referenced point cloud usually generates problems when importing the file in a software like REVIT. For that reason, the point cloud was given with a marked point of reference, which is displaced afterwards (in the modeling software) to its own absolute coordinates.

Fig. 1-49 and Fig. 1-50 show the positioning of all scanning positions during the scanning campaign.

Fig. 1-49: Interior positioning of the laser scanner

Fig. 1-50: Exterior positioning of the laser scanner

The two pictures below (Fig. 1-51) show examples of the 360º pictures that have been extracted from the interior and exterior scans.

(a)

(b)

Fig. 1-51: Examples of 360º pictures taken on site

Fig. 1-52 shows a screenshot of the 3D point cloud that was created.

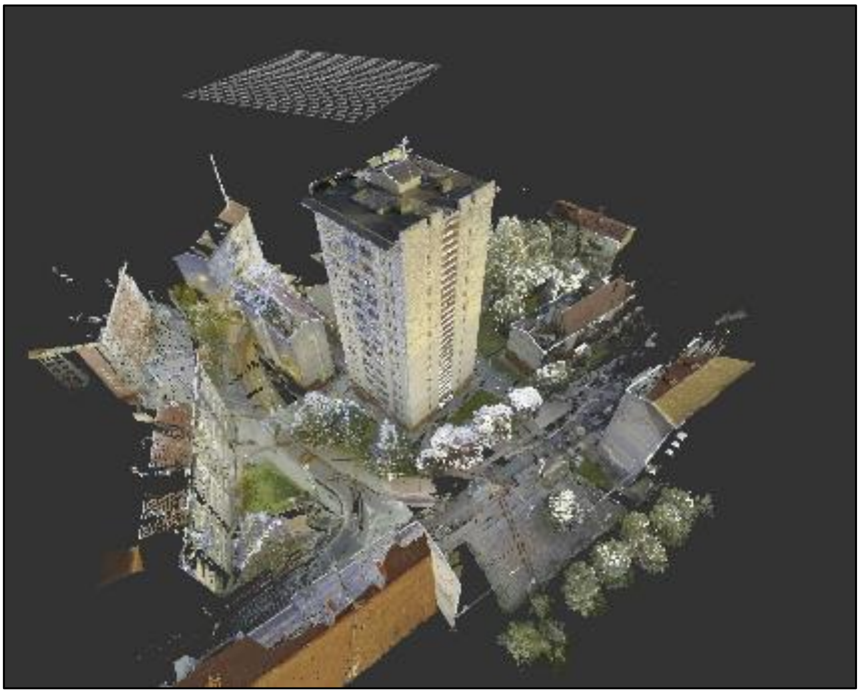


Fig. 1-52: 3D point cloud (with colours) as a result of the laser scanning campaign

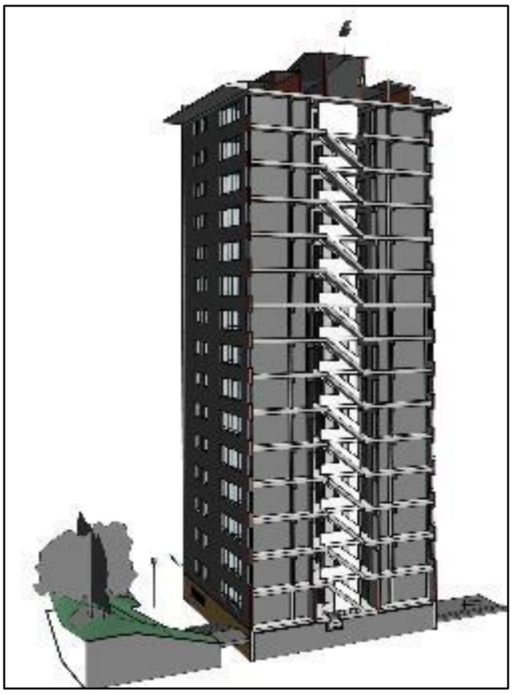
1.3.7.2 BIM MODEL IN REVIT AND IFC EXPORTATION

In October 2021 the BIM Model was created and went through the checks required by all technical partners. As in the case of Polish pilot, detailed guidelines for correct modeling and IFC exportation can be found in [10] and [11].

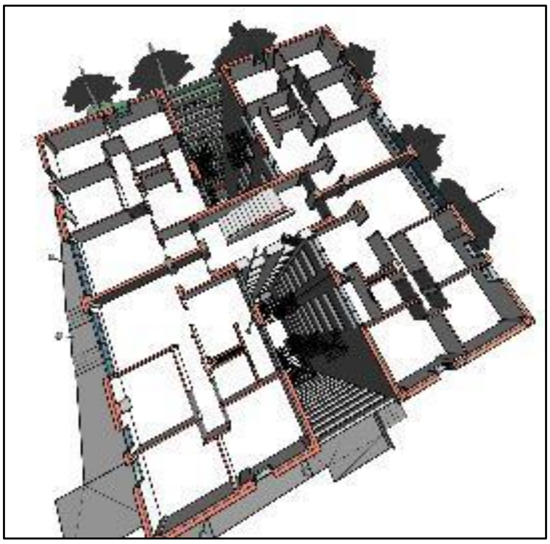
The BIM model creation was subcontracted to the company "Cooperactiva[2]". They are now working on actualizing the BIM model based on the design information shared by the company in charge of the design (Estudio K.). Hence, early 2022, a second version of the BIM Model will be issued, corresponding to the building once the renovation measures have been executed. In other words, there will be two models, the As-is model, and a second one corresponding to the building after the renovation.

In the pictures below (Fig. 1-53) screenshots extracted from the BIM model viewer DALUX are shown.

[2] http://www.cooperactiva.net/



(a) (b)



(c)

Fig. 1-53: Images of the BIM Model.

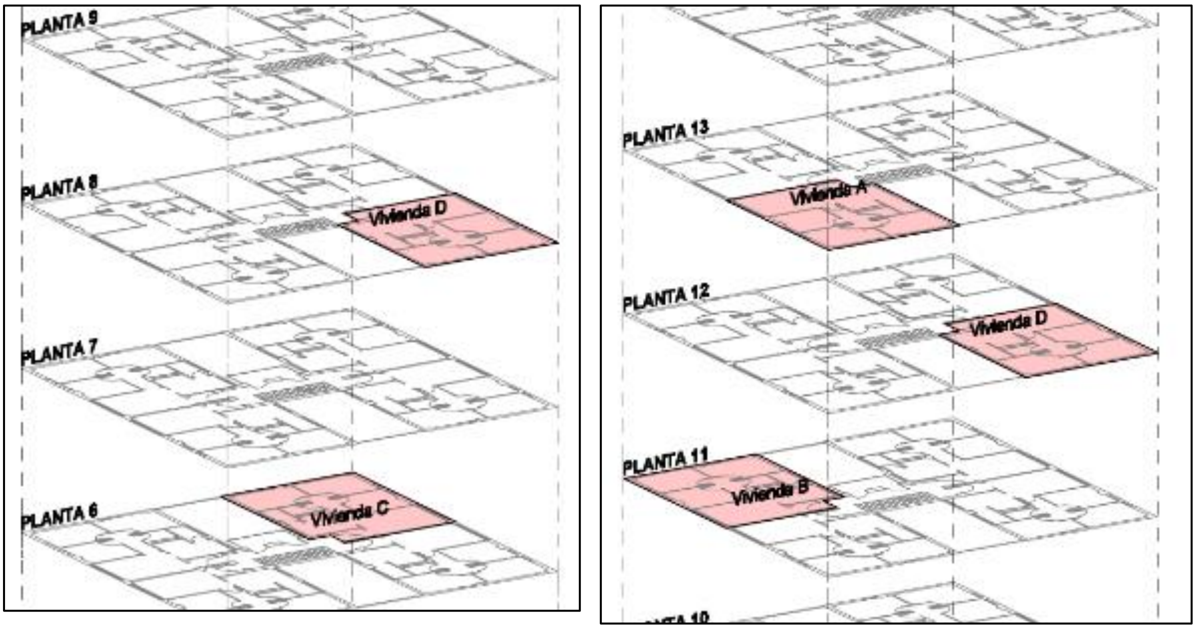
1.3.7.3 VISUAL DATA – IMAGES

Images extracted from the scans, as the ones shown in Fig. 1-51, were processed by BIMERR MEP Object Detection Web Service, which identified and classified HVAC entities (radiators in the case of Larrakoetxe) installed in the different spaces. Fig. 1-54 illustrates a bedroom (scan 9) of the zone "Piso D", where a radiator has been identified (highlighted in pink).

Fig. 1-54: MEP component (radiator) identified in a bedroom of zone "Piso D"

1.3.7.4 Sensing, Monitoring and Metering Data

Based on different criteria established by BIMERR's technical partners (defined in T5.4, especially D5.8), a preselection of flats was made, to fulfill the requirements (flats from all orientation, flats in upper and lower parts, different kind of residents). The figure below shows the respective positioning of these preselected flats: 6C, 8D, 11B, 12D, 13A. The respective consent forms have been signed and uploaded in the project's file repository [14].



(a) (b)

Fig. 1-55: Respective positioning of the preselected flats

The detailed description of the WSN deployment is in T5.4 [6] while below we have summarized the most important information regarding the WSN deployment in the Spanish pilot.

Specifically, the following devices (Fig. 1-56) have been deployed in the flats (the exact number of elements are shown in Table 1-22):

- Home Center Lite (Domotic center with multi-protocol remote access)
- FIBARO Multi sensor 4-en-1 (Movements, temperature, and luminosity)
- FIBARO Door/Window Sensor 2 (Opening detector for doors and Windows)

- FIBARO Wall Plug: Measurement of energy consumption for electric heating
- CO_2 and Temperature with screen indications (230V)
- QUBINO Smart Meter – Electric consumption module plugged in the electric panel

Additionally, Fig. 1-57 presents the metering equipment locations inside a typical flat of the Spanish building.

Fig. 1-56: FIBARO devices installed in the monitored flats

		FLATS					
		6C	8D	11B	12D	13A	*TOTAL*
SENSORS	Home Center	1	1	1	1	1	5
	Temp/Hum/CO2 with display	1	1	1	1	1	5
	Multisensor 4-en-1 Z-Wave Plus (Motion/Luminance/temperature)	6	6	6	6	6	30
	Door/window Sensor 2	7	7	7	8	7	36
	QUBINO SmartMeter	1	1	1	1	1	5
	Wall Plugs	5	2	2	4	3	16
	Total elements per flat	21	18	18	21	19	

Table 1-22: Monitoring devices installed in each flats

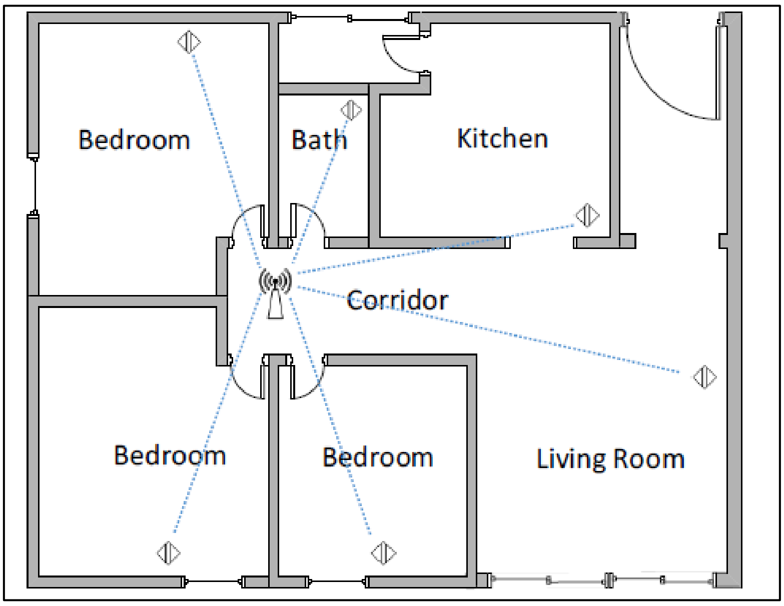


Fig. 1-57: Monitoring equipment's distribution in a typical apartment in the Spanish building

Below are shown some photos of the actual sensors installed in the flats on June 21st, 2021.

(a)

(b)

(c)

(d)

(e)

Fig. 1-58: Pictures of installed sensors: (a) Router, Raspberry and HCL with BIMERR stickers. (b) Qubino Smartmeter in electric panel. (c) window sensors (d) Smartplug. (e) Motion sensor.

1.3.7.5 Weather Data Files – Typical Meteorological Year and Actual Data

Concerning the weather data, weather files can be retrieved from the EnergyPlus climate data webpage. Through this service weather data for more than 2100 locations worldwide, including Europe, are available in a specific format named EnergyPlus weather (epw). These files [15] contain hourly weather observations representing a typical meteorological year, specifically designed for building energy calculations.

The technical Code established a mapping of the Spanish territory (Fig. 1-59).

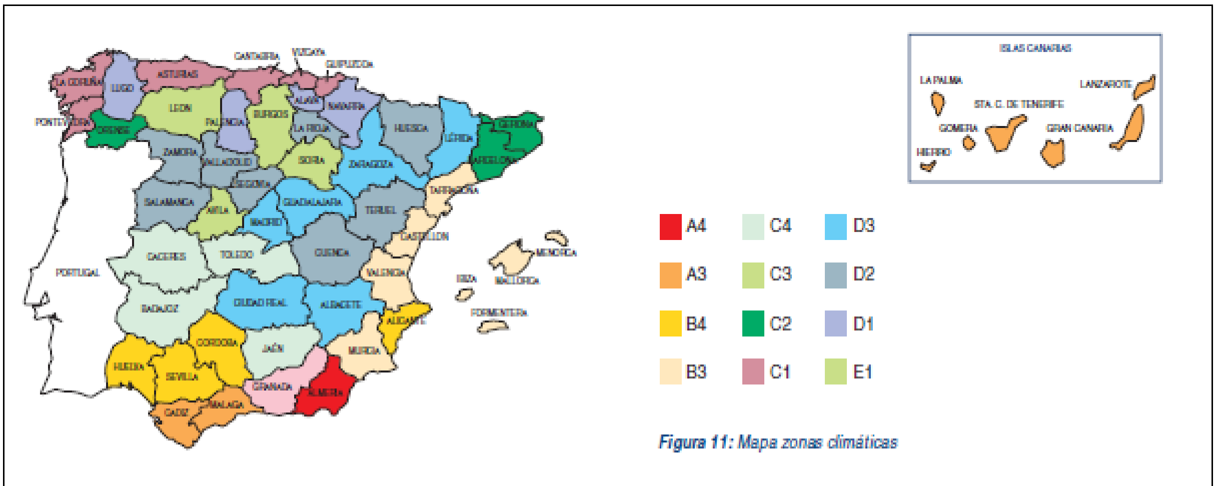


Fig. 1-59: Climate zones in Spain

This climate zoning depends on “climate severity” both in winter and summer, parameters respectively called SCI and SCV, and defined mathematically by different coefficients and weather data. Below, in Tables 1.23 and 1.24 the range of values for each type of climate zone from the Spanish territory are shown.

α	A	B	C	D	E
$SCI \leq 0$	$0 < SCI \leq 0.23$	$0.23 < SCI \leq 0.5$	$0.5 < SCI \leq 0.93$	$0.94 < SCI \leq 1.51$	$SCI > 1.51$

Table 1-23: SCI values for Spain

1	2	3	4
SCV ≤ 0.5	0.5 < SCV ≤ 0.83	0.83 < SCV ≤ 1.38	SCV > 1.38

Table 1-24: SCV values for Spain

The raw climatic data for each region can be downloaded under [16] and [17].

The files are from the type “.MET”. Here are some guidelines to understand how to read the raw data. The “.MET” files are made of lines of text and numbers, structured as follow:

1. The first line (blue colour below) specifies the climatic zone.
2. The second line (red colour below) refers to location information: latitude, longitude, altitude, and reference longitude for the time determination.
3. The third element is composed by all the 8760 following lines (green colour below). The information that can be found is described on Fig. 1-60.

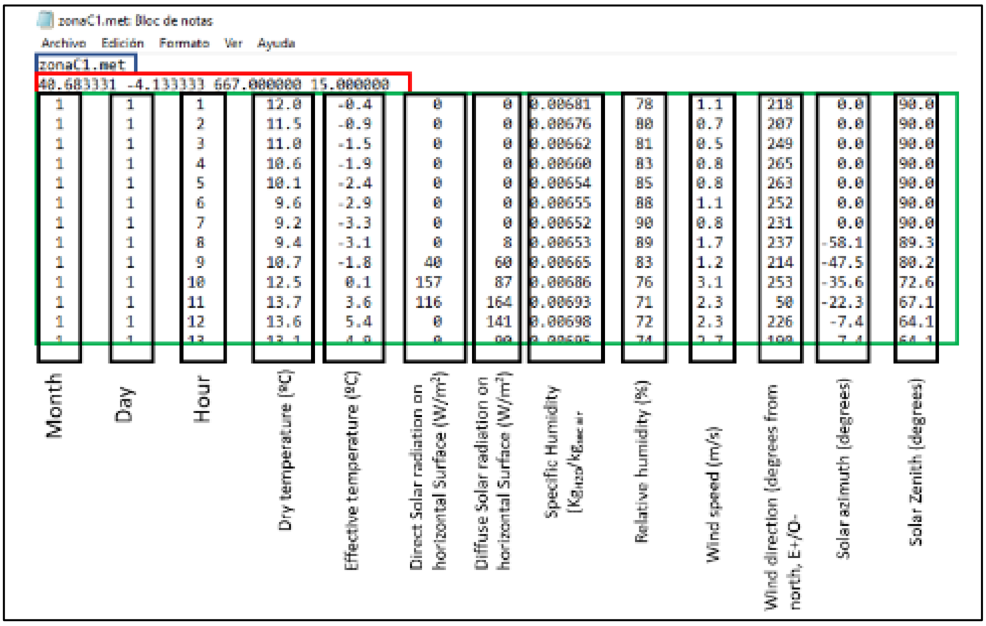


Fig. 1-60: Description of .MET files

1.3.7.6 Cost - Time Baseline data requirements

The Cost and Time KPIs baseline values for the Spanish pilot site follow the same approach used for the Polish pilot site explained in Section 1.2.6.6. The same Excel file was provided containing the KPIs baseline metric and the following table provides a subset of KPIs where their baseline values was provided by the industrial partner.

KPI ID	Metric Name	Description	Value	Notes
CT01	T_{BIM}^{BL}	Time required for creating the BIM model (only geometry).	40h	The requirement for delivering the point cloud is approximately 40h. This is the time needed to create the first viable model that did not match BIM Guidelines. At least additional 40h hours were needed to make all necessary adjustments for the BIM model to match the BIM guidelines (and the checking tools developed in BIMERR).
CT02	$T_{Comp2BIM}^{BL}$	Time required to add an additional energy component to an already created BIM model.	35h	
CT02	N_{Comp}	Number of energy components that are installed in the pilot building.	276 radiators + 1 thermostats	

CT41	$T^{BL}_{AsIsEnrg}$	Time required to complete the as-is energy model with traditional approaches.	3 1/2 months	
CT42	$T^{BL}_{RenScenEv}$	Time required to perform evaluation of different renovation scenarios under the conventional approach.	3 1/2 months	(Designing process: 2 months. Specific research study 1 1/2 month later for IDAE PER
CT35	T_{IEA}	Estimation on time required for a successful information exchange action between stakeholders during phases prior to construction.	3 or 4 months	
CT08	CT08	Number of adjustments to the project schedule after its first finalization.	3	3 adjustments (Open gela review (1) / iso 9001:2015 Ecodesign 14006 test (1+1) / IDEA (1+1)
CT25	$T^{BL}_{as-built}$	Duration of preparing the as-built documentation.	1 month	
ICT01	$T^{BL}_{RenProject}$	Estimation on the time required for renovation project.	1 month	1 month (15 days preliminary sketches / 1 month execution Project Scheme)
ICT02	$C^{BL}_{RenProject}$	Estimation on the cost required for renovation project.	936.725 €	1 month (preliminary information 3 weeks + 2 weeks estudio.k, + 1 week Open Gela review adjustments)

Table 1-25: Spanish Pilot - Data to be used at project evaluation regarding renovation time and cost

1.3.7.7 ENERGY BASELINE DATA REQUIREMENTS

The methodology that has been introduced in Section 1.2.6.7 is also applied for the Spanish pilot site. The Option D of IPMVP is used, that requires calibration of the baseline building energy performance simulation model, using electricity readouts as input (all the energy systems of the Spanish building are electric).

1.3.7.8 RENOVATION MEASURES THAT WILL BE IMPLEMENTED

A first renovation program was undertaken between 1982 and 1989 (facades reparation for waterproofing, change of windows, repair of decks and roofs, structural strengthening, construction of a general drainage network and public lighting for the whole neighborhood). It is noteworthy that this neighborhood is a corner stone of a larger rehabilitation program called Opengela (2019-2022). Opengela is a European innovation project which looks to spread urban regeneration in the Basque Country, creating neighborhood offices which provide advice and support to the neighborhood community. As shown in the Fig. 1-61, the overall energy class of the building is G.

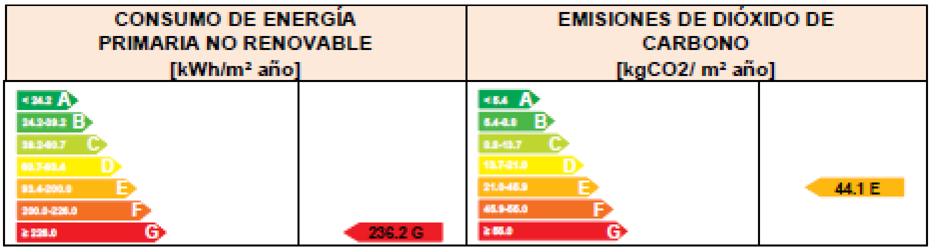


Fig. 1-61: Result of the energy audit – energy consumption (left) and CO2 emissions (right)

The priority measures are the interventions in the roof and the thermal insulation of the facades, and the change of windows. The main objective is to improve the energy characteristics of the building (according to previous Energy Performance Certificate standards, from class G to class C).

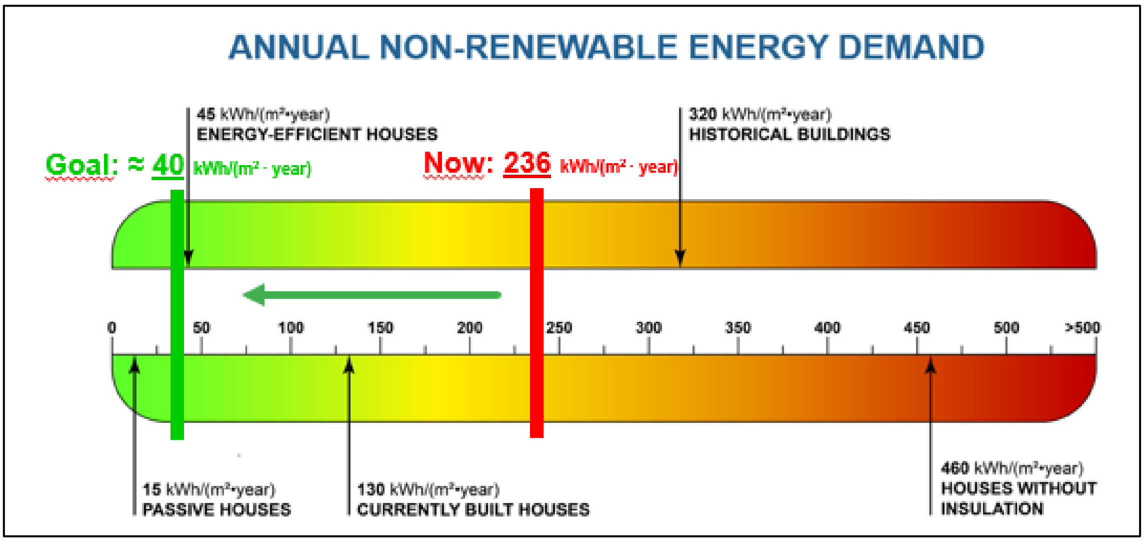


Fig. 1-62: Graphic illustration of the objective set regarding the reduction of energy demand of the building.

To reach that objective, the following main intervention types are planned:

- Improvement of the thermal insulation
- Improvement of the Air Conditioning System (ACS) and heating installations (Viability study of the incorporation of renewable energies).
- To avoid future damages and structural problems, thermal bridges are to be eliminated and it is necessary to ensure a sufficient thermal insulation of the whole building, a reparation and improvement of the façades is needed.
- External carpentry shall also be changed to avoid thermal bridges and condensation.

The overall goal is to improve the thermal insulation, with a reduction of the façade's transmittance, hence reducing the energy demand of the building. In addition, to the improvement of the envelope, improvement of the existing heating installations is planned.

As explained earlier in this deliverable, the facade is made by 4 main facades and by 2 "interior U-Shaped" facades. In the main elements, a ventilated façade is planned, for the 2 "interior U-Shaped" facades, a cheaper solution named "SATE-system" has been chosen. This is shown in the drawing of Fig. 1-63.

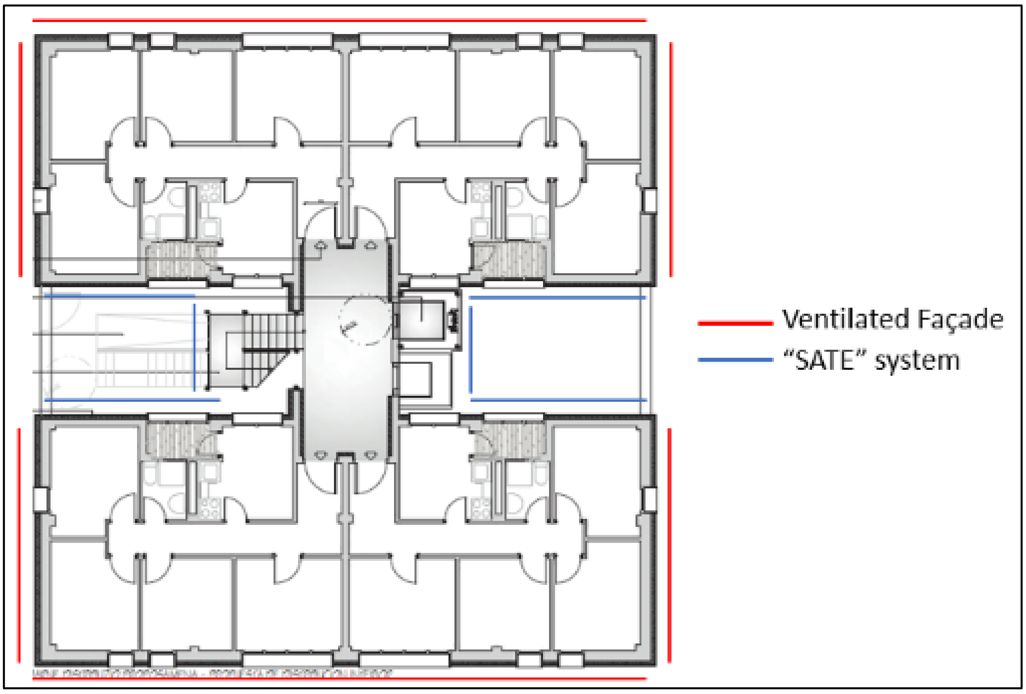


Fig. 1-63: The two different types of façades in the Spanish building

The ventilated façade that is planned to be installed on the existing façade is described both in the chart and the drawing shown below (Fig. 1-64 and Table 1-26).

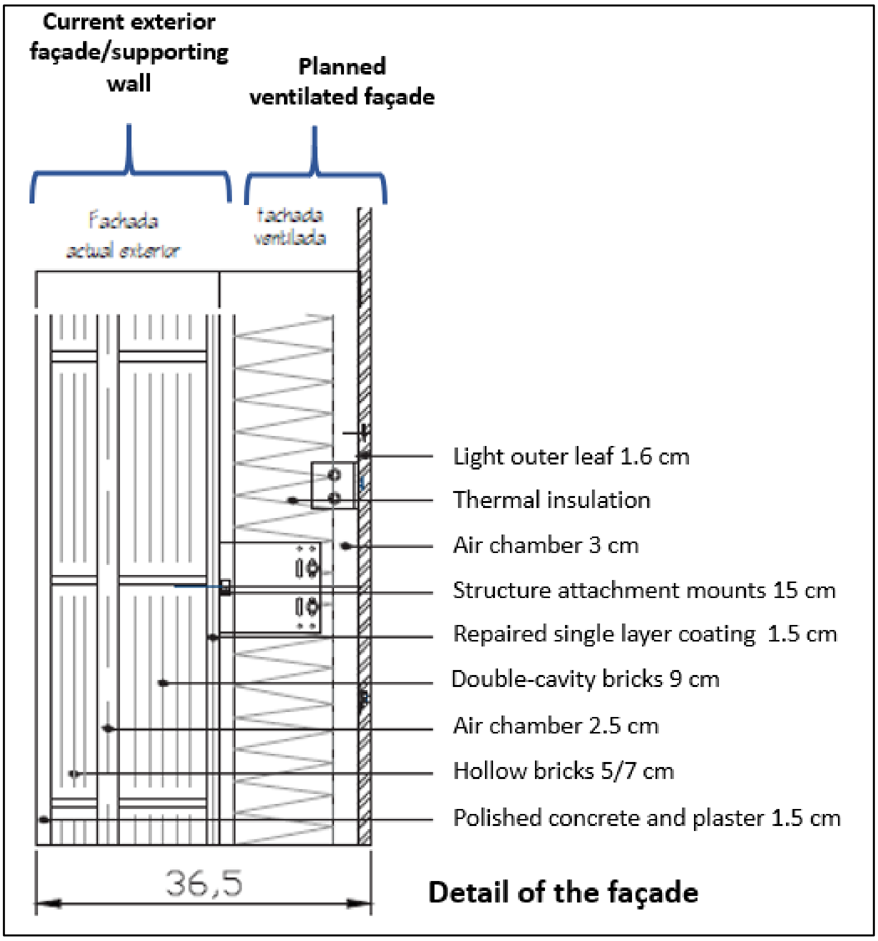


Fig. 1-64: Schematic view of the planned façade layers

Construction type	Material name	Material thickness
External walls (new ventilated façade)	Ceramic piece	1.6 cm
	Air chamber	3 cm
	Windproof barrier TRASPIR 115TT	
	Thermal insulation	12 cm
	vapor waterproof barrier type Vapor 120 TT	
Existing support	Repaired single layer coating	1,5 cm
	Double cavity bricks	9 cm
	Air chamber	2.5 cm
	Hollow bricks	5 or 7 cm
	Inner polished plaster and concrete	1,5 cm

Table 1-26: Layer Material in the façade

Regarding the "SATE-system" that is planned to be installed in the 2 "interior U-Shaped" facades, some basic information can be found in the chart below (Table 1-27).

Construction type	Material name	Material thickness
External walls (new SATE-system)	Finishing plaster	
	Glass fiber reinforcement mesh	
	Thermal insulation plate EPS	10cm
	Metal or plastic anchors	
	Adhesive Mortar	2cm
Existing support	Repaired single layer coating	1,5 cm
	Double cavity bricks	9 cm
	Air chamber	2.5 cm
	Hollow bricks	5 or 7 cm
	Inner polished plaster and concrete	1,5 cm

Table 1-27: Layer Material in "SATE-system"

Regarding the roof, the following drawing and chart (Fig. 1-65 and Table 1-28) outline the planned renovation.

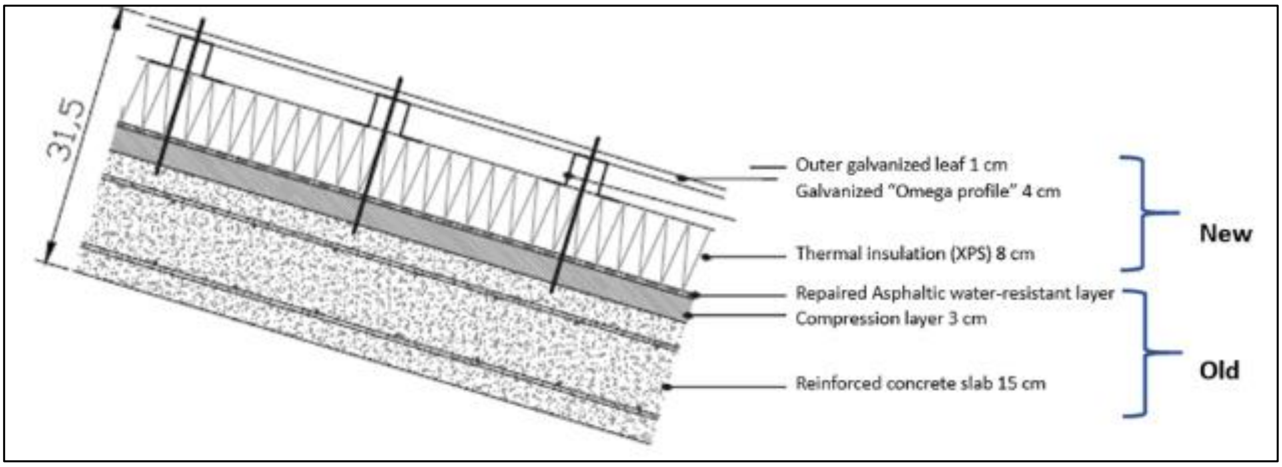


Fig. 1-65: Schematic view of the planned roof layers

Construction type	Material name	Material thickness
Roof (new renovated inclined roof + existing support)	Galvanized metal sheet	1 cm
	Air Chamber with Omega Profile	4 cm
	Thermal insulation XPS	8 cm
	Asphaltic Water-resistant layer	2 cm
	Compression layer	3 cm
	Reinforced concrete slab	15 cm

Table 1-28: Layer Material in the roof

1.3.8 Estimation of a high-level Gantt

The renovation works started on September the 13th 2021, and should last approximately 10 months, so the renovation works will approximately last until summer 2022. A simplified Gantt chart is shown in the next page, while the detailed Gantt chart is provided in the project's file repository in [18].

		2021																2022																											
Months		September				October				November				December				January				February				March				April				May				June				July			
Week		s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4	s1	s2	s3	s4
Rehabilitacion energetica y mejora de la accessibilidad Larrakoetxe 1 Bilbao	215 days																																												
Site preparation	2 days																																												
Main Facade and right-side lateral	99 days																																												
Facade behing and left-side lateral	104 days																																												
Roof	35 days																																												
Lifts	150 days																																												
Fire protection	5 days																																												
Thermal installations	15 days																																												
Staircase Works	10 days																																												
General iron works and locksmithing	35 days																																												
Urban works	5 days																																												
Closing works	3 days																																												

Fig. 1-66: High level GANTT chart of the works at the Spanish pilot.

2 BIMERR PILOT SPECIFIC EVALUATION METHODOLOGY

The project evaluation methodology considers BIMERR impact to the following main categories of interest: renovation total time and cost requirements, energy efficiency, user acceptance, sustainability, and economic potential. Key Performance Indicators (KPIs) have been defined to report BIMERR performance towards the aforementioned categories of interest. Also, a set of impact KPIs has been introduced to demonstrate the project's quantified impact compared against a baseline scenario where the BIMERR ecosystem is not applied.

Evaluation of renovation time and cost reduction

Establishing a methodology for evaluating the BIMERR impact in this category is rather challenging since there are no established guidelines that could be applied directly. In addition, BIMERR focus is on optimizing renovation aspects that span the entire process, from survey to design, planning, execution, construction, and validation. The entire renovation project efficiency with regards to time and cost requirements needs to be evaluated under the BIMERR concept and compared with a hypothetical baseline scenario where the same exact steps are re-taken with traditional approaches.

In our approach, instead of dealing with renovation as a unified process and only measure the two impact KPIs (renovation time reduction, renovation cost reduction), we analyzed the different phases of renovation looking into the specific parameters that affect each one. The milestones along with the bottlenecks that typically appear in each phase are separately evaluated and thus independently represented in the KPIs of this category.

Furthermore, when possible, our approach takes advantage of the repeated nature of many renovation activities especially of the construction phase. Establishing the time/cost gain for an activity (e.g., updating the BIM model), allows us to quantify the time/cost gain for an entire project where the same activity was repeated multiple times.

Therefore, a list of custom KPIs targeting BIMERR's prime objective of optimizing processes throughout the renovation workflow was described. Their main purpose is to calculate time/cost gains from employing BIMERR approaches; note that there are occasions where a single calculation for time/cost gain involves multiple KPIs, therefore, some KPIs are presented as a group (e.g., CT35, CT10, CT32). This way impact indicators (renovation time reduction, renovation cost reduction) are derived by combining individual gains.

The calculations of KPIs in this category are based on WP6 tools and on a hybrid approach where measured values are considered together with simulation data. WP6 has developed tools that

- report time and cost of work-orders attached to specific workflows. So, measurements regarding time and cost can be derived in an automated manner after the proper work-order has been defined and introduced to the Workflow execution engine of WP6 [9].
- model and simulate the renovation process in order to estimate time and cost requirements using historical data and stochastic approaches (Renovation process simulation tool of WP6 [8]).

Evaluation of energy efficiency

The evaluation of the energy efficiency gain achieved with BIMERR is based on the IPMVP guidelines and specifically on Option D for both pilot projects. The reasons [19] that dictated this choice can be summarized as follows: a) several Energy Conservation Measures (ECMs) are considered simultaneously for the energy renovation of both buildings, b) renovation targets the whole building, c) post-renovation measurements will not be available since the operational phase of the buildings after the end of renovation works lies ahead of BIMERR completion date. As a result, the energy efficiency verification via calibrated simulation models as described in Option D arises as the best approach.

The required calibration will be achieved with pre-renovation measurements provided by measurement equipment installed for the purposes of BIMERR (see Sections 1.2.6.4 and 1.3.7.4).

In the framework of BIMERR, tools and modules developed in WP7 deliver the necessary results for the energy efficiency evaluation of the project, i.e., BEP [7] and urban planning modules [20].

Evaluation of sustainability and economic potential

Indicators concerning the financial and sustainability impact of different renovation scenarios are calculated with the LLC/LCA module developed under WP7 activities [21]. The calculations involve not only absolute values but also percentage metrics indicating performance boost with relation to the baseline scenario.

Evaluation of user acceptance

The evaluation of user acceptance (UA) towards BIMERR tools and applications follows the empirical approach described in D3.3, where UA was associated with Perceived Usefulness (PU), Perceived Safety (PS) and Ease of Use (EU). These three axes are addressed with 23 KPIs as presented in Section 2.4.2.

The UA KPIs were mapped to BIMERR main user groups and questions tailored to each of them were derived. The answers provided to the questions were associated to numerical rating values so quantifiable results will be possible.

It should be pointed out that prior to any BIMERR related UA question, each user group will be invited to participate to the system usability scale (SUS) questionnaire. The responses to the SUS questionnaire will be processed separately to get high-level usability results from a well-established and widely used method in system design.

Background

Overall, the first list of BIMERR KPIs was provided on M10 in the context of D3.3 [2], where a high level description for all KPIs along with a rationale specifically for the time and cost KPIs was included. On M24 the pilot projects were selected, and a high-level description of the buildings was made available.

Afterwards, the KPIs list was subjected to an iterative process that involved the BIMERR tool developers and a feedback loop with the pilot partners that provided the necessary updates on the pilot projects. Specifically, there were two rounds of processing, in the first-round partners responsible only for the development of WP6 and WP7 toolkits were engaged in order to be more involved in the measurement approach of each KPI, while the second round was open to all BIMERR partners. This filtering process resulted in updates (removals, additions, modifications) that are presented in the following sections.

2.1 KPI TEMPLATE

Table 2-1 provides the template that will be used for all BIMERR KPIs. Each KPI targets a specific renovation phase, indicated with an X mark on the relevant cell, and belongs to a specific category, indicated in the same way. The field “Input requirements” describes the parameters that need to be known (already calculated or provided) for the KPI to be evaluated, while the field “Measurement approach” describes the tools that are involved in the calculations. Note that the category "Other" describes KPIs that are not targeting the main BIMERR impact axes but are relevant to other technical aspects of the BIMERR toolkit.

ID		Name			
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
Description					
Input requirements					
Measurement approach					
Unit					
Comments					

Table 2-1: BIMERR KPI template

2.2 Cost – Time

2.2.1 Updates to the KPI list of D3.3

The process described in the ***Background*** section of Page 74, resulted in changes to the original list of KPIs included in D3.3. Firstly, 10 KPIs were removed as shown in the following table along with a brief justification.

No	ID	Name	Justification
1	CT05	Number of orders placed and managed in an automated manner during planning process	This KPI is not comparable; procurements will be held with the traditional approaches of the pilot partners and as a result, BIMERR will have no impact on their efficiency.
2	CT06	Number of orders delivered Just-in Time	This KPI lacks comparability with a baseline scenario; a parallel implementation for both traditional and BIMERR approaches would have been otherwise necessary.
3	CT07	Number of automated RFIs (Request for Information) sent during planning process	This KPI is not comparable; procurements will be held with the traditional approaches of the pilot partners and as a result, BIMERR will have no impact on their efficiency.
4	CT09	Response time (averaged over the RFIs sent).	This KPI is not comparable; procurements will be held with the traditional approaches of the pilot partners and as a result, BIMERR will have no impact on their efficiency.

5	CT14	Number of connectivity issues observed, leading to process delays	This KPI goes mainly on the technical (BIF availability vs downtime) side, rather than the impact one.
6	CT16	Time spent in successfully completing the setting up and managing of orders (procurement phase).	This KPI is not comparable; procurements will be held with the traditional approaches of the pilot partners and as a result, BIMERR will have no impact on their efficiency.
7	CT21	Number of change-orders on a process level (due to poor planning) during constructions	This KPI is not comparable; a parallel implementation with traditional as well as with BIMERR tools would have been otherwise necessary.
8	CT22	Number of times that the project completion was rescheduled	This KPI cannot be translated into a workorder, so it is not measurable.
9	CT24	Time spent for completing the assigned tasks	This KPI targets the renovation process at a task level and its measurement is not comparable; CT40 that targets the renovation process at workflow level will be used instead
10	CT28-CT31	Number of incidents occurred during construction - Number of incidents avoided due to proactive information provision -Number of lost-time injuries per million hours worked (LTIFR)	These KPIs relate to Business Scenario (BS) 4 (increase safety for workforce and occupants). Safety increase (BS4) will be evaluated only in the context of user acceptance interviews exploring the perception of safety management of working crews and occupants.

Table 2-2: Cost-Time KPIs that are removed.

On the other hand, indicators that had not been considered in the context of D3.3 were added herein (see next Table).

No	ID	Name
1	CT32	Number of important outputs (data) produced during phases prior to construction
2	CT33	Number of stakeholders involved in phases prior to construction
3	CT34	Time spent for project rescheduling after the detection of a critical issue
4	CT35	Required time for an information exchange action between stakeholders during phases prior to construction
5	CT36	Time spent for setting up workflows
6	CT38	Time required to update the BIM model with modifications
7	CT40	Time spent for completing workflows
8	CT41	Time required to complete the as-is Building Energy Performance model design
9	CT42	Time required to perform the candidate renovation scenarios' evaluation

Table 2-3: Cost-Time KPIs that were added.

Finally, KPIs CT03, CT04 and CT27 of D3.3 were slightly revised and clarified herein.

2.2.2 Template description of Cost-Time KPIs

CT01: Time required to complete the as-is model of the building to be renovated (geometry only)

ID	CT01	Name	Time required to complete the as-is model of the building to be renovated (geometry only).

Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X				
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	BIMERR Scan-to-BIM solution provides a (semi-) automatic approach to produce as-is geometric models of the buildings under renovation. This process is expected to be faster than traditional manual approaches used for the generation of 3D models. The time reduction due to CT01, i.e., RCT01, can be calculated as: $R_{CT01} = T_{BIM}^{BL} - T_{BIM}^{BMR}$ where T_{BIM}^{BL} is the time required for creating the BIM model (geometry only) under the baseline scenario and T_{BIM}^{BMR} is the same metric under the BIMERR scenario. It should be pointed out that the creation of the BIM model for the geometry includes the following: Automatic identification and modelling of structural components, including: walls, slabs, and openings (ie. doors and windows). • Automatic definition of relationships between structural elements, such as storeys, spaces, and second level space boundaries (2LSBs). • Automatic identification and modelling of Mechanical, Electrical and Plumbing (MEP) objects, mainly visible HVAC components. • Automatic check of geometry and 2LSBs by means of BIM-MP. • Manual correction, by means of a third party tool (eg Revit), of the delivered model.				
Input requirements	1. The time required for creating the BIM model (only geometry), i.e., T_{BIM}^{BL}, under the baseline scenario 2. The time required for creating the BIM model (only geometry in BIMERR scenario, i.e., T_{BIM}^{BMR}.				
Measurement approach	Both input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) based on data from pilots and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.				
Unit	Days				
Comments					

CT02: Time required to update the as-is model with complete building information

ID	CT02	Name	Time required to update the as-is model with complete building information		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5

	X				
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	With BIMERR HMD-AR and ARIBFA app the as-is model is accurately updated with energy related equipment, their characteristics and other related hidden components within the building. Some components can be detected automatically through the AR sensors and geometrically modelled and positioned automatically in the BIM model, so that the user only needs to focus on entering any other object information that cannot be obtained visually with the AR cameras. For the traditional process this is done during the technical survey of the building with visual inspection of the building, and subsequent transcription into the project model. Since in the traditional approach of BIM model creation, energy equipment (e.g. radiators) is not included in the BIM model, an estimation of the time needed to add a single or all of the extra components of pilot project into the BIM model is required. BIMERR with the ARIBFA app can semi-automatically add components to the BIM model, so a comparison can be achieved. $R_{CT02} = N_{Comp}\left(T^{BL}_{Comp2BIM} - T^{BMR}_{Comp2BIM}\right)$ where N_{Comp} is the number of energy components that are installed in the pilot building, $T^{BL}_{Comp2BIM}$ is the time required to add an additional energy component to an already created BIM model under the baseline scenario and $T^{BMR}_{Comp2BIM}$ is the corresponding value for the BIMERR scenario.				
Input requirements	1. Time required to add an additional energy component to an already created BIM model under the baseline scenario, i.e. $T^{BL}_{Comp2BIM}$. 2. Time required to add an additional energy component to an already created BIM model under the BIMERR scenario, i.e. $T^{BMR}_{Comp2BIM}$. 3. The number of energy components that are installed in the pilot project (i.e. N_{Comp}).				
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.				
Unit	Days				
Comments					

CT04: Time saved from the issues detected during the first phase of the planning process (before finalizing the project scheduling)

ID	CT04	**Name**	Time saved from the issues detected during the first phase of the planning process (before finalizing the project scheduling)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
				X	
Category					

Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	With the BIMERR Renovation Process Simulation and Formal Verification tool the Project Manager can simulate the planning process and optimize the efficiency of different parameters like time and cost via multiple iterations. In the traditional construction approach, there is no such option available. The project manager, during simulations (see CT03) detects N_{ISS} potential issues (deviations from time and cost projections). These issues would otherwise emerge during the construction phase and could increase the project's duration. The relevant time savings can be calculated as: $R_{CT04} = N_{ISS} \cdot T_{DLY} - CT03$ where T_{DLY} is an estimation of the delay caused to construction works when a planning error occurs. CT03 provides the time required to perform the aforementioned simulations.				
Input requirements	1. Number of total issues detected during the first phase of the planning process (before finalizing the project scheduling), i.e., N_{ISS}. 2. Estimation of the delay caused to construction works when a planning error occurs, i.e., T_{DLY}. 3. KPI CT03 should be defined previously.				
Measurement approach	Both requirements will be provided by tools developed in the framework of WP6 (Workflow Simulation tool) in a manual manner.				
Unit	Days				
Comments					

CT03: Time required to perform the simulations for optimizing renovation process

ID	CT03	**Name**	Time required to perform the simulations for optimizing renovation process		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
				X	
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	In the BIMERR scenario, project manager performs N_{SIM} simulations in order to optimize the renovation process. Each simulation ends with an estimation for total time and cost, and the project manager re-designs key aspects to optimize the result. This KPI calculates the total time requirement (in hours) for the simulations as, $CT03 = N_{SIM} \cdot T_{SIM}$ where N_{SIM} is the number of simulation performed and T_{SIM} is the duration of each iteration.				

Input requirements	1. The duration of simulating the renovation of each pilot (single iteration). i.e., T_{SIM}. 2. The number of iterations required to optimize the time and cost of the planned process, i.e. N_{SIM}.
Measurement approach	The 1st requirement (T_{SIM}) will be provided by Workflow execution engine developed in the framework of WP6 after a properly defined workorder and the 2nd requirement (N_{SIM}) will be decided by the end-user based on experience and pilot's needs.
Unit	Hours
Comments	

CT25: Time spent for preparing the as-built project documentation

ID	CT25	**Name**	Time spent for preparing the as-built project documentation.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	Due to constant updating of the BIM-model with changes (suggested by workers, owners, etc.) during the construction works, the necessary corrections that are traditionally made at the end of the renovation works are now reduced or eliminated. This KPI calculates the time reduction (R_{CT25}) from preparing the as-built documentation. $R_{CT25} = T_{as-built}^{BL} - T_{as-built}^{BMR}$ where $T_{as-built}^{BL}$ is the time spent for preparing the as-built documentation for the baseline scenario, $T_{as-built}^{BMR}$ is the corresponding time for the BIMERR scenario.				
Input requirements	1. The time spent for preparing the as-built documentation for the baseline scenario, $T_{as-built}^{BL}$. 2. The time spent for preparing the as-built documentation for the BIMERR scenario, $T_{as-built}^{BMR}$.				
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.				
Unit	Days				

Comments	1. In the traditional approach the as-built project documentation that includes all the changes that were made during the construction works along with geodesic documentation and recorded as-built geodetic measurements and data, is prepared after the end of renovation works (final step of the renovation process).

CT27: Time spent on scheduling/rescheduling daily activities on the construction site

ID	CT27	**Name**	Time spent on scheduling/rescheduling daily activities on the construction site.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	BIMERR continuous reporting facilitates tracking and scheduling of in progress activities at the construction site. The following expression calculates the time reduction coming from BIMERR more efficient scheduling of daily activities, $R_{CT27} = N_{SchAct} \cdot (T^{BL}_{SchAct} - T^{BMR}_{SchAct})$ where N_{SchAct} is the total number days that daily scheduling of construction activities is required, T^{BL}_{SchAct} and T^{BMR}_{SchAct} is time required for scheduling activities on site with conventional method and BIMERR approach correspondingly.				
Input requirements	1. An estimation on the time required for scheduling activities on site under the baseline scenario, T^{BL}_{SchAct}. 2. Time required to schedule/reschedule activities on a daily basis, T^{BMR}_{SchAct}. 3. Construction phase duration (in days), N_{SchAct}.				
Measurement approach	Input requirements 1. and 2. will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder. Input requirement 3. will be provided directly from the pilot partners after completion of the planning and scheduling activities of pilot projects.				
Unit	Hours				
Comments					

CT34: Time spent for project rescheduling after the detection of a critical issue

ID	CT34	**Name**	Time spent for project rescheduling after the detection of a critical issue

Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	The project manager (or the person responsible for orders, logistic planning etc.) receives alerts for issues that could lead to re-scheduling of the project/workflow; thus, optimizing the route of project implementation. Any issue that was not foreseen during the planning process, forces the project/construction manager to reschedule part of the works. Time spent in successfully rescheduling works is something that BIMERR can have a positive impact on. This KPI allow the evaluation of BIMERR's impact on easier project rescheduling. Time spent for rescheduling the construction project can be reduced in the framework of a BIMERR enabled renovation. The relevant time reduction is calculated as: $R_{CT34} = CT08 \cdot (T_{resc}^{BL} - T_{resc}^{BMR})$ where T_{resc}^{BL} is the time spent for rescheduling the renovation project with the traditional management techniques each time this is required, and T_{resc}^{BMR} is the corressponing time under BIMERR scenario. KPI CT08 represents the total number of times a rescheduling occurs in the actual renovation pilot projects.				
Input requirements	1 The time spent for rescheduling work in the renovation project with conventional methods, i.e. T_{resc}^{BL}. 2. The time spent for rescheduling work in the renovation project with BIMERR approach, i.e. T_{resc}^{BMR}. 3. A value for the KPI CT08 should be defined previously.				
Measurement approach	Input requirements 1. and 2. will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.				
Unit	Hours				
Comments	-				

CT08: Number of adjustments to the project schedule (after project scheduling is finalized)

ID	CT08	Name	Number of adjustments to the project schedule (after project scheduling is finalized)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					

Description	Number of times that the project work plan and scheduling was adjusted to compensate for unforeseen circumstances, e.g., poor weather conditions.
Input requirements	-
Measurement approach	The information will be provided directly from the pilot partners in form of Excel file. A predefined template will be provided to the pilot partner in case of needs.
Unit	-
Comments	1. This KPI is used in the context of time reduction calculations provided by CT34.

CT35: Required time for an information exchange action between stakeholders during phases prior to construction

ID	CT35	**Name**	Required time for an information exchange action between stakeholders during phases prior to construction		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	BIMERR semantic interoperability provision simplifies processes and eliminates the need of paperwork; thus, time savings in the delivery of requested data are expected due to the efficient, high performing and mainly reliable exchange of information. An approximation of the time required for an official project output (such as the architectural design) to be communicated between two stakeholders. The successful communication action may include the initial request for the data, the time elapsed until the request recipient is notified, and any authorizations required, any data preparations and related paperwork, time for getting the data to the requester and time elapsed until notified. When the info is already available at the BIM Platform then the authorized stakeholder can directly access it, otherwise the data needs to be uploaded (see the definition of KPI CT10). Time reduction due to CT35, i.e., R_{CT35}, is considered: $R_{CT35} = N_{IEA}^{max} \cdot (T_{IEA}^{BL} - T_{IEA}^{BMR}) - (CT32 \cdot CT10)$ $N_{IEA}^{max} = CT32 \cdot (CT33 - 1)$ where T_{IEA}^{BL} and T_{IEA}^{BMR} is the time required on average for successful Information Exchange Action (IEA) for the baseline approach and the BIMERR scenario (for info already available at BIM-MP), respectively, N_{IEA}^{max} is the maximum number of information exchange actions among CT32 project outputs and CT33 stakeholders.					

Input requirements	1. An estimation on time required for a successful information exchange action between stakeholders during phases prior to construction, i.e., T_{IEA}^{BL} . 2. Time required for a successful IEA for the BIMERR scenario (for info already available at BIM-MP), i.e., T_{IEA}^{BMR}. 3. KPIs CT10, CT32 and CT33 should be previously defined.
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.
Unit	Hours
Comments	1. Project outputs need to be uploaded to the BIM Platform only once, i.e., CT32·CT10 for the time requirement. 2. The calculation of this KPI can be either based to a single (generic) time requirement for any IEA, or to multiple time requirements, e.g., different durations for different IEAs. In this case, multiple BL ($T_{IEA,i}^{BL}$) and BMR ($T_{IEA,i}^{BMR}$) values need to be defined, along with a slight modification to the R_{CT35} formula to consider this.

CT10: Time for uploading data to the BIF

ID	CT10	**Name**	Time for uploading data to the BIF		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	Practically throughout the renovation process, stakeholders need to upload information to the BIM platform; the semantically enhanced BIM model is uploaded to the BIM Platform during building auditing phase, all the necessary documents for permissioning are also uploaded and information produced after the executive design, such as drawings etc., are also uploaded during permissioning and planning phases. Thus, time required for uploading data is an important KPI.				
Input requirements	-				
Measurement approach	The necessary workorder will be defined in the Workflow Execution engine developed in WP6 to measure the uploading time.				
Unit	minutes				
Comments	1. This KPI is used in the context of time reduction calculations provided by CT35.				

CT32: Number of important outputs (data) produced during phases prior to construction

ID	CT32	Name	Number of important outputs (data) produced during phases prior to construction.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	This KPI supports the evaluation of BIMERR impact on information exchange processes. Important data can be any kind of output that is produced during phases 1-4. For instance: CAD drawings, energy certificates, BIM model, architectural design etc.				
Input requirements	-				
Measurement approach	The value of this KPI will be provided as input to the workflow simulation tool (developed in WP6) by the pilot partners.				
Unit	-				
Comments	1. This KPI is used in the context of time reduction calculations provided by CT35.				

CT33: Number of stakeholders involved in phases prior to construction

ID	CT33	Name	Number of stakeholders involved in phases prior to construction		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	This KPI supports the evaluation of BIMERR impact on information exchange processes and determines the number of people (AEC stakeholders) involved in phases 1-4 (and require any of the data of CT32 in order to complete their work).				
Input requirements	-				
Measurement approach	The value of this KPI will be provided as input to the workflow simulation tool (developed in WP6) by the pilot partners.				

Unit	-
Comments	1. This KPI is used in the context of time reduction calculations provided by CT35. 2. Sample calculation: Let's assume that 1 BIM expert and 2 architects accessed the BIM model, 1 project manager accessed the architectural design. The total number of stakeholders involved is 2+1+1 = 4.

CT38: Time required to update the BIM model with modifications

ID	CT38	**Name**	Time required to update the BIM model with modifications		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	In the context of BIMERR continuous reporting, necessary modifications to the BIM model can be proposed by working crews or building occupants, approved by site managers and finally represented to the BIM model by the architect; all involved stakeholders are notified by the BIMERR PWMA toolkit. This KPI measures the total time requirement from the initial proposal of a BIM modification coming from a member of the working crew to the final update of the model by the architect. $R_{CT38} = CT26 \cdot \left(T_{UpdBIM}^{BL} - T_{UpdBIM}^{BMR}\right)$ In the above expression, T_{UpdBIM}^{BL} and T_{UpdBIM}^{BMR} is the time required to update BIM in the baseline (BL) and BIMERR scenario respectively, while KPI CT26 represents the total number of modifications to the BIM model required during the construction phase.				
Input requirements	1. Time required to update the BIM model with a modification under the baseline scenario (T_{UpdBIM}^{BL}). 2. Measured time for updating the BIM model in BIMERR scenario (T_{UpdBIM}^{BMR}). 3. KPI CT26 should be previously determined.				
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.				
Unit	Hours				
Comments	-				

CT26: Number of updates to the BIM model representing modifications to the original plans that occurred on site

ID	CT26	Name	Number of updates to the BIM model representing modifications to the original plans that occurred on site		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	Number of updates to the BIM model representing modifications to the original plans that occurred on site during construction phase.				
Input requirements	-				
Measurement approach	The information will be provided directly from the pilot partners in form of Excel file. A predefined template will be provided to the pilot partner in case of needs.				
Unit	-				
Comments	1. This KPI is used in the context of time reduction calculations provided by CT38.				

CT40: Time spent for completing workflows

ID	CT40	Name	Time spent for completing workflows		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	During traditional construction approaches, processes involved in typical activities (such as windows installation) were analyzed into tasks on a daily basis by the site/construction manager and assigned to working crews. This KPI calculates the time reduction (R_{CT40}) for the different workflows that will be established and executed with BIMERR. $$R_{CT40} = \sum_{i=1}^{CT20} (T_{WF,i}^{BL} - T_{WF,i}^{BMR} - CT36_i)$$ where $T_{WF,i}^{BL}$ and $T_{WF,i}^{BMR}$ is the time required to complete the i^{th} workflow with the conventional and BIMERR approach respectively, $CT36_i$ is the time requirement for				

	setting up a the i^{th} workflow (see definition of the KPI CT36) and finally $CT20$ is the total number of renovation measures/activities that will be translated into workflows.
Input requirements	1. An estimation of the time required for a specific renovation measure (i^{th} workflow) to be executed, under the baseline scenario, i.e., $T_{WF,i}^{BL}$. 2. Workflow execution time, i.e., $T_{WF,i}^{BMR}$. 3. KPIs CT36 and CT20 should have been calculated earlier.
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.
Unit	Days
Comments	-

CT20: Number of workflows required for the renovation project

ID	CT20	**Name**	Number of workflows required for the renovation project		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	With BIMERR, the processes around the various construction activities will be transformed into workflows that are executed semi-automatically or automatically. Depending on the needs of the renovation project, a number (CT20) of necessary workflows must be set up.				
Input requirements	-				
Measurement approach	The number of different renovation measures that will be implemented (i.e., windows installation, façade insulation, etc.) as executable workflows will be decided in the context of each pilot project and considered in the framework of WP6 with BPMN models.				
Unit	-				

Comments	This KPI is used in the context of time reduction calculations provided by CT40.

CT36: Time spent for setting up workflows

ID	CT36	**Name**	Time spent for setting up workflows		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
					X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	This KPI supports the evaluation of the time requirement for setting up workflows and creating workorders in the context of a BIMERR enabled renovation. $$CT36 = \sum_{i=1}^{CT20} T_{WFS,i}$$ In the previous formula $T_{WFS,i}$ is the time requirement for setting up the i^{th} workflow.				
Input requirements	1. CT20 should be previously defined. 2. The time requirement for setting up a workflow.				
Measurement approach	The time requirement for setting a workflow will be measured by the Workflow execution engine developed in WP6 after a properly defined workorder.				
Unit	Hours				
Comments	1. This KPI is used in the context of time reduction calculations provided by CT40.				

CT41: Time required to complete the as-is Building Energy Performance model design

ID	CT41	**Name**	Time required to complete the as-is Building Energy Performance model design		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					

Description	During the 2nd phase of the renovation process the architect performs studies on the energy performance of the building to be renovated, so any proposal on renovation scenarios can be compared and evaluated against the as-is energy status of the building $R_{CT41} = T^{BL}_{AsIsEnrg} - T^{BMR}_{AsIsEnrg}$ In the previous calculation formula $T^{BL}_{AsIsEnrg}$ is the time required to reach an energy performance evaluation of the as-is status of the building with traditional approaches (baseline scenario), and $T^{BMR}_{AsIsEnrg}$ is the respective time requirement for the BIMERR scenario.
Input requirements	1. Time required to reach an energy performance evaluation of the as-is status of the building under the baseline scenario, i.e. $T^{BL}_{AsIsEnrg}$. 2. Time required to reach an energy performance evaluation of the as-is status of the building under the BIMERR scenario, i.e. $T^{BMR}_{AsIsEnrg}$.
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.
Unit	Minutes/Hours
Comments	

CT42: Time required to perform the candidate renovation scenarios' evaluation

ID	CT42	**Name**	Time required to perform the candidate renovation scenarios' evaluation.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	The architect examines different renovation scenarios with respect to their energy efficiency in order to provide an educated and intriguing proposal to the building owner. BIMERR provides user friendly tools that allow the architect to evaluate and compare renovation scenarios in an easy and time efficient way. Therefore, the relevant time reduction can be calculated with: $R_{CT42} = T^{BL}_{RenScenEv} - T^{BMR}_{RenScenEv}$ where $T^{BL}_{RenScenEv}$ is the time required to perform energy evaluation of different renovation scenarios with traditional tools (baseline scenario) and $T^{BMR}_{RenScenEv}$ is the corresponding time with BIMERR tools.				

Input requirements	1. Time required to perform evaluation of different renovation scenarios under the conventional approach, i.e. $T^{BL}_{RenScenEv}$. 2. Time required to perform evaluation of different renovation scenarios under the BIMERR scenario, i.e., $T^{BMR}_{RenScenEv}$.
Measurement approach	Input requirements will be provided by tools developed in the framework of WP6. The baseline value will be provided by Workflow Simulation tool (manually or otherwise) and the measured value will be provided by Workflow Execution Engine after a properly defined workorder.
Unit	Minutes/Hours
Comments	

ICT01: Reduction of the renovation process duration (%)

ID	ICT01	**Name**	Reduction of the renovation process duration (%)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	This KPI is directly associated with the target BIMERR impacts regarding Time Reduction (TR) according to DoA. There are 11 CT KPIs directly associated with renovation time reduction, i.e. RCT01, RCT02, RCT04, RCT40, RCT25, RCT38, RCT27, RCT34, RCT35, RCT41, RCT42. So, the total renovation time reduction (measured in time units) can be added to: $TR_{RenProject} = R_{CT01} + R_{CT02} + R_{CT04} + R_{CT40} + R_{CT25} + R_{CT38} + R_{CT27} + R_{CT34} + R_{CT35} + R_{CT41} + R_{CT42}$ The % of renovation time reduction includes the baseline value for the entire renovation process that will be calculated via simulation. So, $ICT01 = \frac{TR_{RenProject}}{T^{BL}_{RenProject}} \cdot 100\%$				
Input requirements	1. Calculation of the 11 KPIs CTs should be completed previously. 2. The baseline value for the renovation process duration should be determined, i.e. $T^{BL}_{RenProject}$				
Measurement approach	The baseline value ($T^{BL}_{RenProject}$) will be calculated with the Workflow simulation tool developed in the framework of WP6 modeling the renovation process.				
Unit	%				
Comments	1. Note that the list of KPIs that lead to time reduction may change in the following months as the pilot project progress.				

ICT02: Reduction of the renovation process cost (%)

ID	ICT02	Name	Reduction of the renovation process cost (%)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
X					
Description	This KPIs is directly associated with BIMERR target impact regarding Cost Reduction (CR) and its calculation encompasses the baseline value for the renovation project, and the measured values as they will be measured at both renovation projects. $$ICT02 = \frac{CR_{RenProject}}{C_{RenProject}^{BL}} \cdot 100\%$$ The cost reduction is calculated as: $$CR_{RenProject} = C_{RenProject}^{BL} - \sum C_{RenProject,i}^{BMR}$$ where $C_{RenProject}^{BL}$ is the total cost of the renovation under conventional approaches and $C_{RenProject,i}^{BMR}$ is the cost of the i^{th} workorder as it is defined in the context of BIMERR enabled renovation.				
Input requirements	1. The cost measurement for each workorder that was properly defined for the BIMERR demo activities. 2. The baseline value for the renovation process cost, i.e., $C_{RenProject}^{BL}$				
Measurement approach	The baseline value ($C_{RenProject}^{BL}$) will be calculated with the Workflow simulation tool developed in the framework of WP6 modeling the renovation process. The measured values will be provided by the workorders that will be designed for the pilots.				
Unit	%				
Comments	1. Note that the list of KPIs that lead to cost reduction may change in the following months as the pilot project progress.				

CT11: Number of errors encountered in data received

ID	CT11	Name	Number of errors encountered in data received		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other

					X
Description	During renovation process practically all stakeholders get to upload information to the BIF. This information however is received by other stakeholders (internal or external), therefore tracking the errors encountered in received data is an important KPI. This KPI is not related to the BIMERR impact to renovation CT, but to the accuracy of the tools.				
Input requirements	-				
Measurement approach	The measured value will be provided by BIF.				
Unit	-				
Comments					

CT12: Time needed to fine-tune the semantic mapping

ID	CT12	**Name**	Time needed to fine-tune the semantic mapping		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
					X
Description	The communication between systems owned by different stakeholders is based on semantically interoperable mechanisms, so this KPI will measure the time performance of BIF for fine-tuning the semantic mapping. This KPI is not related to the BIMERR impact to renovation CT, but to the accuracy of the tools.				
Input requirements	-				
Measurement approach	The measured value will be provided by BIF.				
Unit	-				
Comments					

CT13: Number of errors encountered in the semantic mapping of data

ID	CT13	**Name**	Number of errors encountered in the semantic mapping of data		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
					X
Description	The communication between systems owned by different stakeholders is based on semantically interoperable mechanisms, and semantic mapping of data may be subject to errors. This KPI is not related to the BIMERR impact to renovation CT, but to the accuracy of the tools.				
Input requirements	-				
Measurement approach	The measured value will be provided by BIF.				
Unit	-				
Comments					

CT15: Number of incidents allowing unauthorized access to data

ID	CT15	**Name**	Number of incidents allowing unauthorized access to data		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	X	X	X	X	X
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
					X
Description	BIMERR provides the Building Information Secure Provisioning Tool that is used for specific data access policies referring to the access rights of each stakeholder to the building information available in the BIF to be defined. As a result, each time a stakeholder tries to build a query regarding building information the aforementioned access policies need to be respected. This KPI is not related to the BIMERR impact to renovation CT, but to the accuracy of the tools.				
Input requirements	-				

Measurement approach	The measured value will be provided by BIF.
Unit	-
Comments	

2.3 ENERGY

This category gathers KPIs that are not only related to the building energy efficiency, but also to the environmental and economic performance of the renovation measures.

2.3.1 Updates to the KPI list of D3.3

The process described in the ***Background*** section of page 74, resulted in changes to the original list of KPIs included in D3.3. Firstly, 10 KPIs were removed; the following table lists these KPIs along with a brief justification.

No	ID	Name	Justification
1	OC01	Mean Vote difference for thermal comfort	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
2	OC04	Humidity Preferences Not Met While Occupied Time	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
3	OC05	Indoor air quality preferences Not Met While Occupied Time	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
4	OC06	Percentage Dissatisfied difference with thermal comfort	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
5	OC07	Mean Vote difference for indoor air quality improvement	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
6	OC08	Percentage Dissatisfied difference for indoor air quality improvement	This KPI targets the operational phase of the renovated building which is out of BIMERR main scope.
7	SU8	Water pollution	This KPI is not supported by BIMERR tools; there are other sustainability related KPIs that are supported.
8	SU9	Air pollution	This KPI is not supported by BIMERR tools; there are other sustainability related KPIs that are supported.
9	EC3	Increase in rental rate of building	This KPI is not supported by BIMERR tools; there are other economic KPIs that are supported.
10	EC4	Increase of resale rate of building	This KPI is not supported by BIMERR tools; there are other economic related KPIs that are supported.

Table 2-4: Comfort, sustainability and economic KPIs that are removed.

On the other hand, indicators that had not been considered in the context of D3.3 were added herein (see Table 2-5)

No	ID	Name
1	EC5	Construction cost
2	EC6	Operation cost during period of analysis
3	EC7	Maintenance cost during period of analysis
4	EC8	End of life cost
5	EC9	Life cycle cost during period of analysis

Table 2-5: Economic KPIs that were added.

Finally, modifications to the KPIs list of D3.3 were also derived during the processing rounds. Specifically:

- KPIs EE7-EE10 were split in two, i.e., EE7a, EE7b, …,EE10a, EE10b, to have a single parameter measured by each KPI.
- KPI EE18 was rephrased to target specifically CO2 emission rate instead of the initial generic definition of GHG.

2.3.2 Template description of Energy related KPIs

EE1: Total primary energy consumption

ID	EE1	**Name**	Total primary energy consumption		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Primary energy consumption refers to the direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains, and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	$kWh/m^2/year$				
Comments					

EE2: Total primary energy consumption non renewable

ID	EE2	**Name**	Total Primary Energy Consumption non Renewable		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5

		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Primary energy consumption for non-Renewables refers to the direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains, and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	kWh/m^2/year				
Comments					

EE3: Electric energy consumption

ID	EE3	**Name**	Electric energy consumption		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The building total electric energy consumed for the operation of HVAC systems, lighting and appliances.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				

Unit	kWh/m²/year
Comments	

EE4: Natural gas energy consumption

ID	EE4	**Name**	Natural gas energy consumption		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The building total natural gas energy consumed for the operation of HVAC systems and appliances.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	kWh/m²/year				
Comments					

EE5: District heating energy consumption

ID	EE5	**Name**	District heating energy consumption		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				

Description	The building total district heating energy consumed for the operation of HVAC systems and domestic hot water equipment.
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS
Unit	kWh/m^2/year
Comments	

EE6: Consumption of other fuel types

ID	EE6	**Name**	Consumption of other fuel types		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Fuel types such as diesel, biomass energy consumption.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	kWh/m^2/year				
Comments					

EE7a: Peak heating load

ID	EE7a	**Name**	Peak heating load		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Maximum/peak value of heating profile.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	Watts				
Comments					

EE7b: Heating load profile

ID	EE7b	**Name**	Heating load profile		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The heating load profile for a specific period of time in Watts.				

Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS
Unit	Watts
Comments	

EE8a: Peak cooling load

ID	EE8a	**Name**	Peak cooling load		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Maximum/peak value of cooling profile.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	Watts				
Comments					

EE8b: Cooling load profile

ID	EE8b	Name	Cooling load profile		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The cooling power profile for a specific period of time.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	Watts				
Comments					

EE9a: Heating energy demand

ID	EE9a	Name	Heating energy demand		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Energy demand required to heat the building.				

Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.
Unit	kWh/m²/year
Comments	

EE9b: Cooling energy demand

ID	EE9b	**Name**	Cooling energy demand		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Energy demand required to cool the building.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	kWh/m²/year				
Comments					

EE10a: Electricity load profile

ID	EE10a	**Name**	Electricity load profile		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The electricity load profile for a specific period of time in Watts.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS				
Unit	Watts				
Comments					

EE10b: Peak electricity load

ID	EE10b	**Name**	Peak electricity load.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Maximum/peak value of electricity profile.				

Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.
Unit	Watts
Comments	

EE11: PV electric energy generation

ID	EE11	**Name**	PV electric energy generation		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The electric energy generated by photovoltaic panels installed in the building – to be discussed if pv installations will be candidate renovation measures.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	kWh/m^2/year				
Comments					

EE12: Solar thermal energy generation

ID	EE12	**Name**	Solar thermal energy generation		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	The thermal energy generated by solar thermal panels installed in the building – to be discussed if solar thermal panel installations will be candidate renovation measures.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	kWh/m^2/year				
Comments					

EE13: Electrical energy generated in the district and used onsite

ID	EE13	**Name**	Electrical energy generated in the district and used onsite		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Electrical energy generated in district and used in building.				

Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.
Measurement approach	District energy calculation by urban planning module based on BEP module output and user-provided data regarding energy production/consumption of surrounding buildings.
Unit	kWh/m²/year
Comments	

EE14: Energy generated on site and exported to the district

ID	EE14	**Name**	Energy generated on site and exported to the district.		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Excess energy generated on site and exported to district.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing occupant behavior data for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	District energy calculation by urban planning module based on BEP module output and user-provided data regarding energy production/consumption of surrounding buildings.				
Unit	kWh/m²/year				
Comments					

EE15: Absolute annual energy savings

ID	EE15	Name	Absolute annual Energy Savings		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Aggregate annual energy saving at premises				
Input requirements	Baseline and renovation scenario energy KPIs				
Measurement approach	KPI supported by RenoDSS				
Unit	kWh/m^2/year				
Comments					

EE16: Relative annual energy Savings (percentage)

ID	EE16	Name	Relative annual energy Savings (percentage)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Percentage reduction of energy need.				
Input requirements	Baseline and renovation scenario energy KPIs				
Measurement approach	KPI supported by RenoDSS				
Unit	%				
Comments					

EE17: Reduction of peak energy load (percentage)

ID	EE17	**Name**	Reduction of peak energy load (percentage)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Reduction of peak energy load.				
Input requirements	Baseline and renovation scenario peak energy load KPIs				
Measurement approach	KPI supported by RenoDSS				
Unit	%				
Comments					

EE18: CO2 emissions reduction (percentage)

ID	EE18	**Name**	CO2 emissions reduction (percentage)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
	X				
Description	Describes the CO2 emission reduction per square meter floor area caused by the lowered energy consumption because of implemented renovation measures. The reduction is calculated by comparing the renovation scenario to the baseline scenario in terms of CO2 emissions.				
Input requirements	CO2 emission rates of baseline and renovation scenario which are calculated as follows: $$CO2 = \frac{\sum_{i=1}^{n} CO2_i * EC_i}{A}$$ CO2 is the CO2 emission rate in kg CO2 per square meter floor area of the building				

	i	is the current energy carrier (power, oil, gas, district heating, etc.)
	n	is the number of energy carriers used in the building
	$CO2_i$	is the CO2 emission rate in kg of energy carrier i per kWh
	EC_i	is the energy consumption of the building regarding energy carrier i in kWh
	A	is the floor area of the building
Measurement approach	$$CO2_{red} = \left(1 - \frac{CO2_{reno}}{CO2_{base}}\right) * 100$$ where $CO2_{base}$ and $CO2_{reno}$ is the CO2 emission rate before and after the renovation respectively. The KPI is calculated by the LCA/LCC module based on the IFC file and input from the building material and component database.	
Unit	%	
Comments		

OC02: Heating desired temperature not met while occupied time

ID	OC02	**Name**	Heating Desired Temperature Not Met While Occupied Time		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
		X			
Description	Percentage of time that the occupants' max temperature preferences were not met.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing heating thermal comfort bounds for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	%				
Comments					

OC03: Cooling desired temperature not met while occupied time

ID	OC03	Name	Cooling Desired Temperature Not Met While Occupied Time		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
		X			
Description	Percentage of time that the occupants' min temperature preferences were not met.				
Input requirements	• Static data – Valid IFC file containing second-level space boundaries, materials' thermal properties, internal gains and HVAC components' energy related properties. • Dynamic data – Valid ObXML file containing heating thermal comfort bounds for each space, generated by the PRUBS component, and receiving occupants' feedback using the BICA application. • Weather data – Valid EnergyPlus weather data file (EPW) containing weather information for a typical meteorological year; extreme summer and winter days must be included.				
Measurement approach	Building energy simulation by BEP module based on IFC, EPW, and obXML files provided by RenoDSS.				
Unit	%				
Comments					

SU1: Global warming potential

ID	SU1	Name	Global Warming Potential		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Describes how much heat a greenhouse gas traps in the atmosphere in 100 years relative to carbon dioxide. For example, the CO_2 equivalent of methane over a period of 100 years is 28. I.e., one kilogram of methane contributes in the first 100 years to the greenhouse effect like 28 kilogram CO_2.				

Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties.
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database *GWP100a* is provided for the life cycle of each building material and component used in the renovation measures by its reference unit. The total global warming potential per square meter floor area of a renovation measure is calculated by: $$GWP100a = \frac{\sum_{i=1}^{n} GWP100a_i * RU_i}{A}$$ GWP100a — is the global warming potential of the renovation measure in kg CO2-eq i — is the current building material or component used in the renovation n — is the number of materials or components used in the renovation $GWP100a_i$ — is the global warming potential of material or component i per reference unit (e.g., 0,45 kg CO2-eq per m³) RU_i — is the amount of reference units of material or component I (e.g., 27 m³) A — is the floor area of the building
Unit	kg CO2eq/ m^2
Comments	

SU2: Depletion potential of the stratospheric ozone layer

ID	SU2	**Name**	Depletion potential of the stratospheric ozone layer		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Indicator of emissions to air that cause the destruction of the stratospheric ozone layer.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties.				
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$ODP = \frac{\sum_{i=1}^{n} ODP_i * RU_i}{A}$$				

	where *ODP* Is the relative amount of degradation to the ozone layer a chemical compound can cause, with CFC-11 fixed at an ODP of 1 *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure *RUᵢ* is the amount of reference units of material or component I (e.g., 27 m^3) A is the floor area of the building
Unit	kg CFC-11 eq/m^2
Comments	

SU3: Acidification potential of soil and water

ID	SU3	**Name**	Acidification potential of soil and water		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Acidification potential describes the amount of acids emitted to the atmosphere and subsequently deposited in soil and water[3] in the context of the life cycle of materials and components used in the renovation measures per square meter floor area.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties				
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$AP = \frac{\sum_{i=1}^{n} AP_i * RU_i}{A}$$ where *AP* Acidification potential *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure				

[3] https://www.sciencedirect.com/topics/engineering/acidification-potential

	RUi	is the amount of reference units of material or component I (e.g., 27 m³)
	A	is the floor area of the building
Unit	kg SO2 eq/ m2	
Comments		

SU4: Eutrophication potential

ID	SU4	**Name**	Eutrophication potential		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Eutrophication occurs when an ecosystem is saturated with essential non-organic nutrients such as nitrogen and phosphorus compounds, which under natural conditions would only normally be present in small concentrations. When released into water, these substances trigger outbreaks of algae and aquatic plants, which, in turn, leads to a shift in the biodiversity of the ecosystem [22]. The eutrophication potential of the nutrient input is specified in kg (PO4)3- -eq (phosphate equivalent) per square meter floor area.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties.				
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$EP = \frac{\sum_{i=1}^{n} EP_i * RU_i}{A}$$ where *EP* Eutrophication potential *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure RU_i is the amount of reference units of material or component I (e.g., 27 m³) *A* is the floor area of the building				
Unit	kg PO4 eq/ m2				

Comments	

SU5: Formation potential of tropospheric ozone

ID	SU5	**Name**	Formation potential of tropospheric ozone		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Quantifies the relative abilities of volatile organic compounds (VOCs) to produce ground level ozone [23]. Specified in kilograms ethylene per m² per square meter floor area.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties				
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$POCP = \frac{\sum_{i=1}^{n} POCP_i * RU_i}{A}$$ where *POCP* Formation potential of tropospheric ozone *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure RU_i is the amount of reference units of material or component I (e.g., 27 m³) *A* is the floor area of the building				
Unit	kg ethylene/ m2				
Comments					

SU6: Abiotic depletion potential for non-fossil fuels resources

ID	SU6	**Name**	Abiotic depletion potential for non-fossil fuels resources		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					

Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Refers to the depletion of non-living (abiotic) non-fossil resources and is measured in kilograms of Antimony equivalents [24] per square meter floor area.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties.				
Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$ADPE = \frac{\sum_{i=1}^{n} ADPE_i * RU_i}{A}$$ where *ADPE* Abiotic depletion potential for non-fossil resources *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure RU_i is the amount of reference units of material or component I (e.g., 27 m^3) *A* is the floor area of the building				
Unit	kg antimony/m^2				
Comments					

SU7: Abiotic depletion potential for fossil fuels resources

ID	SU7	**Name**	Abiotic depletion potential for fossil fuels		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Refers to the depletion of non-living (abiotic) fossil resources and is measured in kilograms of Antimony equivalents [24] per square meter floor area.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant material and HVAC component properties.				

Measurement approach	Calculated by LCA/LCC module based on the volume of relevant building material and components and their sustainability impact properties which are stored in the BIMERR material and component database $$ADPF = \frac{\sum_{i=1}^{n} ADPF_i * RU_i}{A}$$ where *ADPF* Abiotic depletion potential for fossil resources *i* is the current building material or component used in the renovation measure *n* is the number of materials or components used in the renovation measure RU_i is the amount of reference units of material or component I (e.g., 27 m^3) *A* is the floor area of the building
Unit	MJ/ m^2
Comments	

SU10: Environmental Cost Indicator

ID	SU10	**Name**	Environmental Cost Indicator		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
			X		
Description	Indicator that unites all relevant environmental impacts into a single score of environmental costs, representing the environmental shadow price of a product or project.				

Input requirements	Availability of KPIs SU1 - SU9 and environmental shadow prices of each KPI, e.g.: **KPI** / **Unit** / **Monetary unit/unit** SU2 GWP100a total global warming potential / kg CO2-eq / 0,05€ SU3 Acidification potential of soil and water (AP) / kg SO2-eq / 4,00€ SU4 Depletion potential of the stratospheric ozone layer (ODP) / kg CFC / 30,00€ SU5 Abiotic depletion potential for non-fossil resources (ADPE) / kg Sb-eq / 0,16€ SU6 Eutrophication potential (EP) / kg PO4-3 eq / 9,00€ SU7 Abiotic depletion potential for fossil resources (ADPF) / kg Sb-eq / 0,16€ SU8 Formation potential of tropospheric ozone (POCP) / kg C2H4-eq / 2,00€
Measurement approach	Calculated by LCA/LCC module based on the KPIs SU1, SU2, SU3, SU4, SU5, SU6, SU7, SU8, SU9, and their environmental shadow prices.
Unit	€/m²
Comments	

EC1: Return on Investment (ROI)

ID	EC1	**Name**	Return on Investment (ROI)		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	ROI assessment of energy by using the overall investment costs and the saving in energy running costs over a defined period of time.				
Input requirements	Construction cost of the renovation scenario, maintenance and energy running cost of baseline and renovation scenario.				
Measurement approach	The ROI is calculated by dividing the reduced operational costs by the overall investment costs. $$ROI = \left(\frac{(ec2_{base} + ec3_{base}) - (ec2_{reno} + ec3_{reno})}{ec1_{reno}}\right) * 100$$ ROI is the Return of Investment in % $ec2_{base}$ is the energy running cost during the period of analysis for the baseline scenario				

	$ec2_{reno}$	is the energy running cost during the period of analysis for the renovation scenario with applied renovation measures
	$ec3_{base}$	is the maintenance cost during the period of analysis for the baseline scenario
	$ec3_{reno}$	is the maintenance cost during the period of analysis for the renovation scenario with applied renovation measures
	$ec1_{reno}$	are the construction cost of the renovation scenario
Unit	%	
Comments		

EC2: Payback Period

ID	EC2	**Name**	Payback Period		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	Estimated by the ratio of investment costs over the yearly savings in energy running costs.				
Input requirements	Construction cost of the renovation scenario, maintenance and energy running cost of baseline and renovation scenario.				
Measurement approach	According to ISO 15686-5:2017 the payback period is calculated as the number of years elapsed between the initial investment (construction cost), its subsequent operating cost and the time at which cumulative savings offset the investment. The payback period is the time it takes to recoup the initial investment of an alternative to the base case.				
Unit	Years				
Comments					

EC5: Construction cost

ID	EC5	**Name**	Construction cost		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5

		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	The construction costs of a renovation measure include the costs for (i) removing the old component or layers of the construction and (ii) purchasing and installing the new renovation measure (including taxes).				
Input requirements	Valid IFC file containing second-level space boundaries and relevant financial material and HVAC component properties.				
Measurement approach	$$CC = \sum_{i=1}^{b}(DC_i + CC_i)$$ CC are the construction cost of the renovation measures i is the current renovation measure b is the number of renovation measures applied to the building DC_i is the disposal cost which occur prior installing renovation measure i CC_i is the construction cost for renovation measure i including material and installation The costs are stored per reference unit of the renovation measure for each component or each layer of the construction. The reference unit (e.g., m² or m³) of each layer is multiplied with the material and installation cost stored for this specific context-, scenario-, material- and thickness context in the cost and linking table.				
Unit	MU				
Comments					

EC6: Operation cost during period of analysis

ID	EC6	**Name**	Operation cost during period of analysis		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	Operation cost includes energy costs (including taxes) for heating and cooling the building. According to standard ISO 15686-5:2017 it takes expected the energy escalation rate and discount rate in terms of opportunity cost into account. Note that the energy costs are calculated for each energy carrier to take each one's escalation rate and consumption into account.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant financial material and HVAC component properties.				

Measurement approach	$$OC = \sum_{i=1}^{b}\sum_{n=0}^{a} \frac{EDi_n * EPi_0 * (1+e_i)^n}{(1+d)^n}$$ OC are the present value operation cost during the period of analysis b is the number of energy carriers used in the building i is the current energy carrier a is the period of analysis (30 years per default) n is the number of years between the base data and the occurrence of the cost EDi_n is the energy demand of energy carrier i in year n EPi_0 is the energy price of energy carrier i in year 0 e_i is the expected energy escalation rate of energy carrier i d is the expected discount rate
Unit	MU
Comments	

EC7: Maintenance cost during period of analysis

ID	EC7	**Name**	Maintenance cost during period of analysis		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	Maintenance cost includes costs that occur to maintain renovation measures and replace them after their lifetime during the period of analysis (including taxes). In case of constructions the maintenance costs include all renovated layers, in case of components the component itself.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant financial material and HVAC component properties.				
Measurement approach	$$MC = \sum_{i=1}^{b}\sum_{n=0}^{a} \frac{(MCi_0 + CCi_0) * (1+e)^n}{(1+d)^n}$$ MC are the present value maintenance cost during the period of analysis b is the number of renovation measures applied to the building i is the current renovation measure a is the period of analysis (30 years per default) n is the number of years between the base data and the occurrence of the cost MCi_n is the maintenance cost of renovation measure i in year n CCin is the construction cost for replacing renovation measure i after its lifetime in year n e is the expected escalation rate for construction and maintenance cost				

	d is the expected discount rate
Unit	MU
Comments	

EC8: End of life cost

ID	EC8	**Name**	End of life cost		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	End of life cost include disposal of the renovation measure after its lifetime (including taxes). Please note that this value can be negative if the residual value exceeds the cost of disposal.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant financial material and HVAC component properties.				
Measurement approach	End of life cost = *sum of disposal cost for renovated construction layers or component* $$EoLC = \sum_{i=1}^{b} \frac{EoLCi_0 * (1+e)^n}{(1+d)^n}$$ EoLC are the present value end of life cost during the period of analysis i is the current renovation measure b is the number of renovation measures applied to the building $EoLCi_0$ is the end of life cost of renovation measure i in year 0 e is the expected escalation rate for end of life cost n the last year of the period of analysis (30 years per default) d is the expected discount rate				
Unit	MU				
Comments					

EC9: Life cycle cost during period of analysis

ID	EC9	Name	Life cycle cost during period of analysis		
Renovation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
		X			
Category					
Cost-Time	Energy	Comfort	Sustainability	Economic	Other
				X	
Description	Life cycle cost is the sum of the renovation measure's present value construction, operation, maintenance, and end of life costs. Note that the lifetime of renovation measures is not homogeneous and can be below or above the period of analysis.				
Input requirements	Valid IFC file containing second-level space boundaries and relevant financial material and HVAC component properties.				
Measurement approach	Sum of the renovation measure's present value construction, operation, maintenance, and end of life costs.				
Unit	MU				
Comments					

2.4 USER ACCEPTANCE

2.4.1 *Updates to the KPI list of D3.3*

The list of UA KPIs was slightly updated compared to D3.3; Table 2-6 summarizes the changes.

No	ID	Name	Modification/Justification
1	UA19	Level of annoyance due to noise	This KPI was removed since it is out of BIMERR's scope
2	UA20	Level of annoyance due to vibrations	This KPI was removed since it is out of BIMERR's scope
3	UA21	Level of annoyance caused by materials occupying surfaces	This KPI was removed since it is out of BIMERR's scope

Table 2-6: Changes to the list of UA KPIs

2.4.2 *UA KPIs*

Perceived Usefulness		
KPI	Definition/Description	Main User Group
UA1	Productivity improvement	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker

UA2	Increase in the efficiency of task completion	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker
UA3	Improvement in decision making	Architect, Project Manager, Site Manager, Worker
UA4	Improvement in collaboration among teams	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker
UA5	Improvement in communication among peers and stakeholders	Project Manager, Site Manager, Worker
UA6	Improvement of architectural design quality due to the enriched and more accurate BIM models produced	Architect
UA7	Increase in the sense of accountability among stakeholders	Site Manager, Project Manager
UA8	Improvement in the perceived easiness in information exchange and tracking	Architect, Project Manager, Site Manager, Occupant
UA9	Improvement in the perceived accuracy in bidding estimations	Project Manager
UA10	Improvement in the perceived easiness in management of change-orders during construction phase	Project Manager, Site Manager
UA11	Reduction in the level of intrusion experienced by occupants during renovation	Occupant
UA12	Increase in monitoring capabilities offered to stakeholders during renovation works	Project manager, Site manager, Worker, Occupant
UA13	Completeness of information exchanged with the BIF	Architect, Project Manager, Site Manager
UA14	Perceived security in data accessibility	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker, Occupant
UA15	Overall added value offered through the BIF	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker, Occupant
Perceived Safety		
KPI	Definition/Description	Main User Group
UA16	Improvement in perceived safety at construction site	Worker, Site Manager, Occupant
UA17	Improved safety communications in the construction site	Worker, Site Manager, Occupant
UA18	Working crews' level of satisfaction with management commitment to H&S	Worker, Site Manager
Ease of Use		
KPI	Definition/Description	Main User Group
UA22	Level of difficulty in learning to use BIMERR tools	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker, Occupant

UA23	Level of intuitiveness in user interfaces	Architect, BIM modeler, Project manager, Site manager, Surveyor, Worker, Occupant
UA24	Easiness in the use of semantic mapping tools	Architect, BIM Modeler, Project Manager, Surveyor
UA25	Level of guidance comprehensiveness for facilitating semantic mapping	Architect, BIM Modeler, Project Manager, Surveyor
UA26	Easiness in the creation of queries for data search	Architect, Project Manager, Site Manager

3 BIMERR TOOLS PILOT ACTIVITIES – DEMONSTRATION SCENARIOS

This section describes the demonstration activities of BIMERR and follow the five business scenarios that were established during the earlier phase of the project in D3.1 [1]. Section 3.1 provides a short description of the most important lessons learnt during the pre-validation activities [11] and Sections 3.2 - 3.6 analyze each demonstration scenario with respect to the involved BIMERR tools, the enablers and possible blockers, the KPIs and finally, the specific planning of a demonstration test case in accordance with the pilot activities.

3.1 LESSONS LEARNED FROM PRE-VALIDATION ACTIVITIES

The conclusions reached during the pre-validation phase provided feedback for better planning of demo activities. The valuable lessons learned for each BIMERR tool, during the pre-validation phase are:

- **WSN Installation**

The installation of BIMERR wireless sensor network (WSN) can be challenging. Physical access should be ensured during the installation in the validation sites in case any hard reset of the equipment is required. Specific definition of the name of each room and each sensor should be provided during the sensor commissioning and setup to avoid revisits. An issue that should also be considered is the visual disturbance of the occupants by the LEDs for visual notification installed on each motion sensor.

- **BIMERR Middleware**

The requirement gathering and design of a uniform access control mechanism should start at the beginning of the technical activities to produce a secure by design architecture. The WSN design of the pre-validation sites should closely reflect the one from the pilot sites to avoid technical failures. It is important to consider all issues and the experience with respect to the WSN hardware and software in pre-validation as the basis for the design of pilots. Bulk software deployment tooling should be installed and used from the very beginning to be able to easily scale when large scale deployments begin.

- **Scan-to-BIM**

The use of different Terrestrial Laser Scanning (TLS) devices for the digital documentation of buildings results in varying outcomes (i.e., point clouds). A number of parameters, either chosen by the user (e.g., resolution) or intrinsic to the device (e.g., accuracy, precision), impact the quality of the cloud delivered by the scanning system, and ultimately the scan-to-BIM algorithm performance. The quality of the data affects the segmentation of spaces and, therefore, the identification of wall surfaces. Another important aspect to be carefully considered is the pre-processing (mainly registration and cleaning) of the point clouds obtained by the scan. The strategy followed in the Scan-to-BIM tool for identifying openings is challenged in the case of windows or doors that are not opened or occluded.

- **BIMERR Interoperability Framework (BIF)**

Required updates were performed or additional concepts were added in the data models, using the Model Lifecycle Manager, to cover the data exchange needs of the BIMERR applications during the pre-validation activities. Processes should be defined and agreed by the partners at project level regarding the management and identification of the various versions of a data asset. The BIMERR applications should appropriately setup multiple data collection jobs leveraging the functionality of BIF to send data as text accompanied by a binary file with an API request. Data provided by the applications to the BIF need to follow a consistent structure within their whole extent, and according to the initial data sample provided during the configuration of the data collection job.

- **BIM Management Platform (BIM-MP)**

During the pre-validation activities, modifications were applied on BIM-MP's GED tool to handle cases where openings were not exported correctly (the opening volumes were extended beyond their wall's internal or external surfaces). The development of the embedded 3D model viewer helped the designer identifying the geometric errors more easily. The multiple files that BIM-MP produces for each model checking and geometric checking are better organized in different file repositories per revision and not per project. The naming of the generated files is based on ISO 19650 for better management of the local copies.

- **Augmented Reality Enabled in-situ Building Feature Annotation (ARIBFA)**

The registration accuracy for large buildings could benefit by splitting the 3D model to floors and using an image target per floor. Keyboard functionality that can be tedious to the user was minimized. A strong Wi-Fi network is needed to perform the object detection functionality of the ARIBFA tool, since the Hololens are paired to a local computer on the same network. The object detection functionality can also be affected by the speed of the user's movement since there is already latency in the procedure due to pairing of the Hololens to a local machine. Since the application runs on a device with relatively small CPU and RAM specifications (Hololens), the IFC editing functionality is challenging.

- **Profiling Resident Usage of Building System (PRUBS)**

Demonstration experiments of PRUBS functionalities during the pre-validation phase streamlined the communication and data exchange of PRUBS with other BIMERR components (Middleware and BIF). To perform the co-simulation between EnergyPlus and the obXML, the obXML must be populated in a way that information about the IfcSpace, IfcZone and IfcBuilding GUIDs is included. Specific data requirements and guidelines were communicated to the Middleware developers so that the BIMERR metadata of the IoT would be capable on providing information about the relevant attributes.

- **Building Information Collection Application for Building Residents (BICA)**

The points to be addressed in the context of the BIMERR integrated platform are the complete workflow of user authentication/authorisation and identification of the relevant apartments involving Keycloak, the retrieval of sensor data from Middleware and the identification of those that apply to the specific BICA user using the provided Keycloak token, and the retrieval of the specific user's estimate comfort status from BIF through the setup of an appropriate search query that will utilise the Occupancy data model (based on data coming from PRUBS).

- **Renovation Decision Support System (RenoDSS)**

Mapping missing building material properties is sufficiently supported by the BIMERR material and component database. Mapping missing building component was not a straightforward process as components differ a lot depending on their release year and the market that they were launched in. Financial data of existing material and components for the LCA/LCC module (maintenance cost and disposal cost) were hard to obtain. While RenoDSS provided renovation measure materials out-of-the-box, renovation measures components had to be added for the specific buildings (e.g., a heating system that fits the building). The automated renovation scenario generation and KPI calculation compensate the effort of the initial data gathering required by RenoDSS, compared to manual or semi-automated scenario generation and KPI calculation.

- **BIMERR Process & Workflow Modelling and Automation (PWMA)**
    - Renovation Process Generation

Regarding the Renovation Process Generation activities in the pre-validation, the integration with the PWMA execution engine component and the integration with the BIMERR RenoDSS Toolkit were successfully validated. The simulation component of the PWMA could use predefined simulation parameters for each process template that need only minor adaptations when a specific renovation process, that is instantiated from that template, must be simulated. The usage of predefined template for the renovation process models reduced significantly the effort required in the definition of the two scenarios.

- PWMA For Managers

The PWMA For Managers deemed to be sufficient and effective as a general tool for managing workflows, workorders, and users.

- PWMA For Workers

The workorder loading and execution worked fine without any apparent problems. The Notification System also didn't expose any design or implementation flaws and provided a seamless and effective usage. Overall, the lesson learned is that both the Worker's application and Notification system are sufficient for the work in the field, provided that the users are introduced to them and taught the work routines within them.

- PWMA For Residents

The management of the received data worked well, and all the data related to the user were displayed during the functionality tests in the pre-validation sites. Regarding the issue reporting and task commenting functionality, the data was collected successfully and prepared properly for uploading it to BIF. Uploading multiple attachments per issue might be challenging and needs further consideration.

3.2 Demo Scenario 1: based on Business Scenario 1

Demo Scenario 1 (DS1) is based on Business Scenario 1 and its goal is to assist construction companies and/or architectural studios in design procedures, reducing time, and subsequently costs, in renovation projects.

3.2.1 Tools involved

DS1 includes two use cases, namely UC-01 and UC-02. As detailed in the following, each UC has a particular aim and involves diverse tools.

UC-01 is connected to the generation of BIM models, which are initially produced by the Scan-to-BIM tool and then, completed and corrected by BIM modelers.

UC-02 includes tasks aiming to complete the BIM model produced in UC-01 and involves ARIBFA and BICA tools.

Although not explicitly mentioned above, the Building Interoperability Framework (BIF), BIMERR – Management Platform (BIM-MP) and the Middleware are also involved in the demo scenarios, since these are essential for communication between tools.

3.2.2 Test cases per tool

3.2.2.1 Enablers

For UC-01, the enablers are:

- Input data (i.e., point clouds and images) acquired according to the defined Scan-to-BIM specifications and
- Working communication between the Scan-to-BIM and BIM-MP tools (through the BIF)

For UC-02, the enablers are:

- The input BIM model, produced either through UC-01 or manually using traditional modelling practice, and
- Working communication between the tools (i.e., ARIBFA and BICA) and BIM-MP or between BICA and PRUBS for the exchange of occupancy data (through the BIF).

3.2.2.2 Probable Blockers

Amongst probable blockers, impeding the ideal functioning of the tools, the following may arise:

For UC-01, any inappropriate input point cloud (and imagery), and specifically, potential issues that are related to resolution of both pictures and clouds, and incompleteness or inaccuracy of point clouds may be a blocker.

For UC-02, three possible blockers can be identified:

1. A failure of Scan-to-BIM to produce a broadly accurate and complete model
2. Restricted access to apartments and/or to an Internet connection.
3. Potential issues with occupants, who may be reluctant or have difficulties to use the BIMERR app on smartphones

Note that some mitigation solutions have been identified for all the identified blockers. For example, BIM models of both pilot sites have been generated manually using traditional practice to mitigate for the first blocker and, the BICA app can by-pass the deficiency of available data, by completing some missing information with default values regarding room names.

3.2.2.3 KPIs Associated with the Test Case

A number of KPIs are related to DS1. CT01, which measures the time to complete the geometry of the building, is associated with UC-01; CT02, corresponding to the time to update the model with energy equipment, is linked to UC-01 and UC-02.

In both UC-01 and UC-02 additional User Acceptance (UA) KPIs are measured, these are: UA1 for productivity improvement, UA2 for the efficiency of task completion, UA4 for the collaboration among teams, UA14 (perceived security in data accessibility), UA15 (added value offered through the BIF), and finally UA22-25 that target the ease-of-use aspect of the developed tools.

3.2.2.4 Test Case Planning

UC-01

For validation purposes, BIM models are produced following two different approaches, as shown in Fig. 3-1. The main difference is that, in Flow 1 (red arrow) a first version of the BIM model is created entirely manually by the BIM modeler, while in Flow 2 (green arrow) the initial BIM model is delivered by the Scan-to-BIM tool. In both cases, the initial model is then checked by the BIM-MP, to identify potential errors, and corrected manually by the modeler (by means of ArchiCAD/Revit) until a BIM model free of errors is produced.

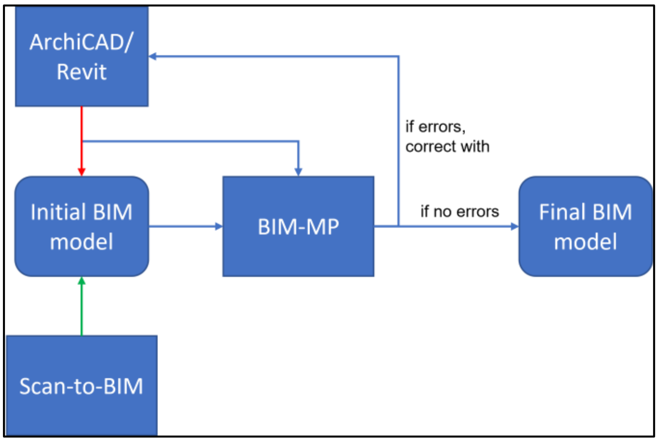


Fig. 3-1: Generation of BIM models in BIMERR

The Gantt chart in

UC-01																	
Task	Responsible	15/11/21	22/11/21	29/11/21	6/12/21	13/12/21	20/12/21	27/12/21	3/1/22	10/1/22	17/1/22	24/1/22	31/1/22	7/2/22	14/2/22	21/2/22	28/2/22
Integration with the BIF	UEDIN																
Scan-to-BIM tool	UEDIN																
Communication with BIM-MP	UEDIN-UCL																
Agreed KPI CT01 measurement	UEDIN-FER-BX																
Training material for model correction	UEDIN																
Spanish site BIM model available	FER																
Spanish site full point cloud (floor)	UEDIN-FER																
Spanish site BIM modeller participation (training + correction)	FER-UEDIN																
Polish site BIM model available	BX																
Polish site full point cloud	UEDIN-BX																
Polish site BIM modeller participation (training + correction)	BX	Agreed															

Fig. 3-2 illustrates the planning for DS1 UC-01 activities. Amongst already completed tasks (in green), there are: the integration/communication between Scan-to-BIM and other tools (i.e., BIF and BIM-MP); the (manual) generation of BIM models for both pilot sites. Ongoing activities (in yellow) include: the refinement of the Scan-to-BIM tools and the generation of point clouds for both pilot sites, which implies the creation of data for several apartments by using existing reliable data (i.e., minimised occlusions, adequate resolution), since all the apartments are not in the same condition and the quality of the point clouds is not homogeneous. And finally, the pending works (red) comprise: the production of training material for the correction of BIM models, the agreement with the BIM modelers on the measurement of KPIs, and the activities involving the modelers regarding the correction of errors in the Scan-to-BIM models.

UC-01																	
Task	Responsible	15/11/21	22/11/21	29/11/21	6/12/21	13/12/21	20/12/21	27/12/21	3/1/22	10/1/22	17/1/22	24/1/22	31/1/22	7/2/22	14/2/22	21/2/22	28/2/22
Integration with the BIF	UEDIN																
Scan-to-BIM tool	UEDIN																
Communication with BIM-MP	UEDIN-UCL																
Agreed KPI CT01 measurement	UEDIN-FER-BX																
Training material for model correction	UEDIN																
Spanish site BIM model available	FER																
Spanish site full point cloud (floor)	UEDIN-FER																
Spanish site BIM modeller participation (training + correction)	FER-UEDIN																
Polish site BIM model available	BX																
Polish site full point cloud	UEDIN-BX																
Polish site BIM modeller participation (training + correction)	BX	Agreed															

Fig. 3-2: Gantt chart for UC-01 tasks

UC-02 - ARIBFA

With ARIBFA, the BIM modeler using appropriate equipment (Hololens AR glasses) firstly loads the BIM model of the building. To address the complexity of the multi-storey pilot buildings, a menu is displayed in the application for the user to select the specific storey where the evaluation of the tool will be performed. Two show cases will be performed: in the first, the BIM model is downloaded from the BIF and in the second, the BIM model is loaded from the application's folder on Hololens internal storage to avoid the download overhead and minimize the required processing required on site.

When the BIM model is loaded, the BIM modeler performs registration to align the 3D BIM model to the real world. Since the registration process relies on image markers, the user is prompted to view at the printed image marker that is beforehand placed at specific common areas of the storey, e.g., near the stairs. Subsequently, the BIM modeler enters the flat to be used for evaluation, adds annotations to building components and performs the MEP detection to add missing components to the BIM model. The process of loading the error-free BIM model from BIM-MP and enriching the BIM model to include missing MEP components is illustrated in Fig. 3-3.

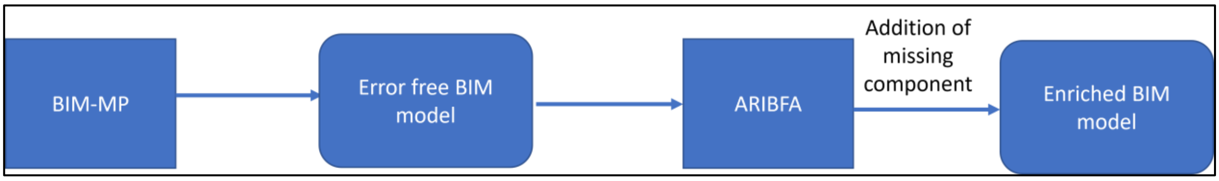


Fig. 3-3: The pipeline used for ARIBFA to receive and enrich the BIM model

The Gantt chart in Fig. 3-4 illustrates the planning for DS1 UC-02 activities for ARIBFA. Amongst already completed tasks (in green), there are: the integration/communication between ARIBFA and other tools (i.e., BIF and BIM-MP). Ongoing activities (in yellow) include: the refinement of the ARIBFA tool and the generation of training material. And finally, the pending works (red and blue) comprise: the agreement on the measurement of KPIs, the arrangement for a laptop on pilot sites with installed the Desktop ARIBFA application, the arrangement for having internet connection during evaluation activities, the securing of access to one flat in each pilot building, and activities for training the persons to perform the evaluation of the ARIBFA tool. Regarding the initialisation of markers (used in the localization functionality of the ARIBFA tool) on the pilot sites, image markers will be placed only on the storeys of the empty flats to be used for evaluation activities. After concluding on which flats (therefore storeys) will be available for testing the tool, detailed instructions will be provided regarding the position to place the image markers and how to print them to maintain the aspect ratio. For this task, the blue colour indicates the date planned for this task for the Polish pilot site while the red indicates the date planned for the Spanish pilot site.

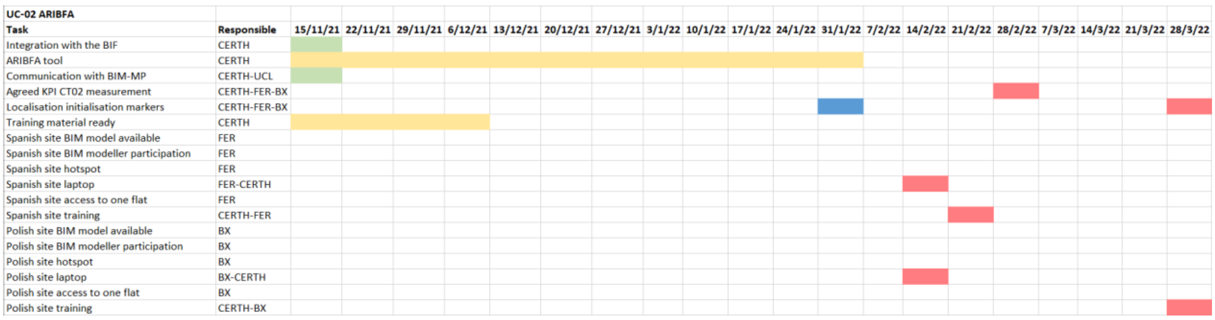


Fig. 3-4: Gantt chart for UC-02 tasks for ARIBFA

UC-02 BICA

Through BICA the residents can display information about their apartments (rooms, installed appliances), their estimated comfort status, the current ambient conditions in specific rooms and view reported issues related to their apartment. Additionally, they can actively provide information that will assist in renovation design, planning and in the enhancement of the captured BIM information, by creating issues about problems in their apartments (and binding them to specific components), by providing additional information about their apartments (such as the preferred usage of rooms and any missing components information in the form of free text) and by defining their actual comfort status in the current ambient conditions (thus enabling personalised renovation design). Although the BICA app does not perform direct updates to the BIM data model, the provided information is available to other BIMERR apps and the designers from the side of the renovation company through BIF, that can use this information for optimized renovation design.

As depicted in Fig. 3-5, during this scenario, the BICA app will get BIM data for the resident's apartments and occupancy behavior estimations, provided by BIM-MP and PRUBS respectively through BIF. Concurrently, sensor data is consumed through the Middleware. The residents will view this information through the BICA UI. Then they will create new Issues, add the relevant tag (e.g., Health and Safety, Maintenance, Other, etc.), bind the issues to a specific room or component (or leave them at apartment-level), attach photos and finally add their comments in free text. These issues are propagated to the BIF, from where they are available to the interested BIMERR tools. Additionally, the users will browse the 'Report Log' of their apartments to view issues created by them or by other residents that live under the same apartment. Finally, the users will update the displayed estimated comfort status within a room (using a five-level scale) to match their actual comfort status. These updates are bound to the related room and the current ambient conditions and are again sent to BIF, from where they are available to other BIMERR tools.

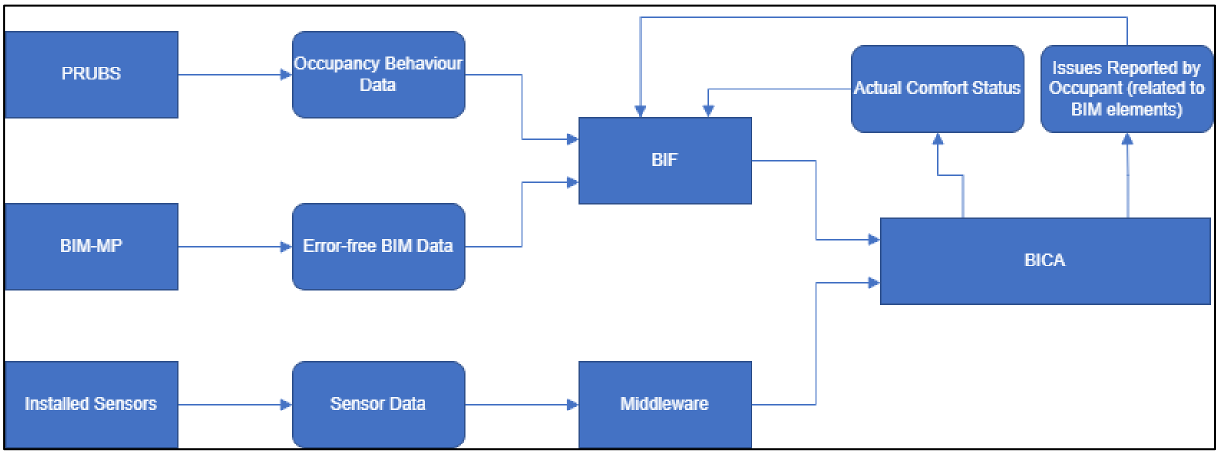


Fig. 3-5: Pipeline for the provision of additional BIM and comfort information by residents through BICA

Fig. 3-6 represents the Gantt chart for the planned tasks towards the demonstration of DS1 UC-02 BICA. Tasks that have been successfully completed are marked with green and include the confirmation of the BICA use case within DS1, the provision of training material (including a user manual and a demo video), and the confirmation of participation of residents in the Spanish pilot site. In yellow highlight the tasks that are already in progress are depicted and a rough estimation of their duration until reaching completion is provided. In the case of the integration of BICA with BIF and Middleware for the consumption of data, the integration from a technical perspective has been completed and tested (with the pre-validation sites data). However, the specific tasks are not yet marked as complete and their duration is provided with a question mark, due to the dependency on availability of the final pilot sites' BIM data, for which there is currently no fixed date. The BICA tool will be appropriately updated based on the final integration and testing activities and will be available for download to the end users on time for the training activities. Finally, tasks that have not started yet and have an estimated date are denoted with red. These include the final tasks towards the pilot activities, including the training of the residents, the on-site testing of the network availability (with the possibility of requiring a hotspot if the already envisioned solutions do not cover the connectivity needs of the pilots), and the preparations for the provision of company mobile phones - in the case of the Polish pilot site.

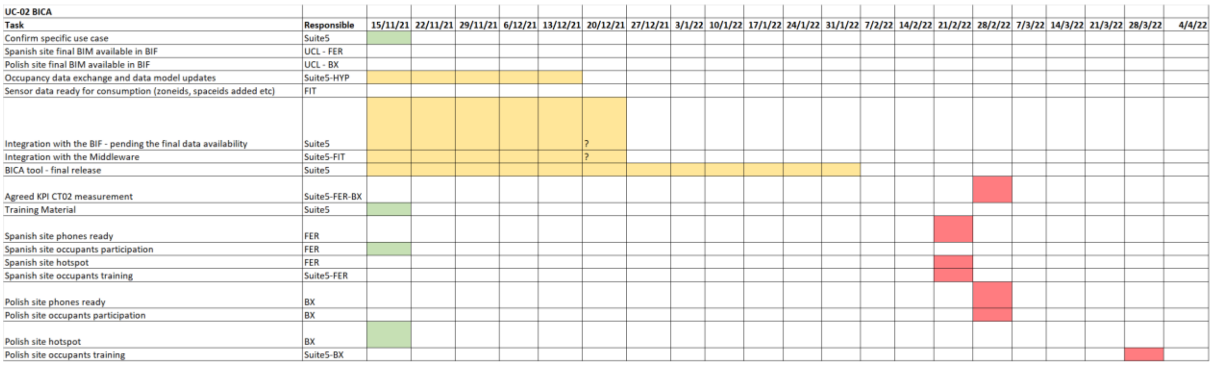


Fig. 3-6: Gantt chart for UC-02 tasks for BICA

3.3 DEMO SCENARIO 2: BASED ON BUSINESS SCENARIO 2

Demo scenario 2 is based on Business Scenario 2 and its goal is to reduce the time and cost of project planning processes (from permissions to materials order) through standards-based communication with all involved stakeholders.

3.3.1 Tools involved

DS2 includes UC-05 and UC_06 use cases (UC-07 that is also included herein, is not supposed to be demonstrated but it is an enabler to the other use cases).

UC-05 supports accurate scheduling of activities and assessment of their efficiency through simulation and verification using *Workflow modelling and simulation tool* and *PWMA tool*.

UC-06 supports process automation and execution on a workflow-based approach using PWMA with its Notification system tool and Workflow modelling and simulation tool.

Although not explicitly mentioned above, the Building Interoperability Framework (BIF), BIMERR – Management Platform (BIM-MP) and the Middleware are also involved in the demo scenarios, since these are essential for communication between tools.

3.3.2 Test cases per tool

3.3.2.1 ENABLERS

The only enabler for UC-05 is the initial schedule and the renovation measures from the pilot sites. Regarding UC-06,

- the initial schedule from the UC-05 in form of a BPMN file and
- the fully functional BIF integration (schedule/workorder upload + building components download).

are both required.

3.3.2.2 PROBABLE BLOCKERS

Incomplete integration with the BIF is considered as the only blocker for UC-06. There are no blockers for UC-05.

3.3.2.3 KPIs ASSOCIATED WITH THE TEST CASES

Key Performance Indicators (KPIs) related to DS2 are CT03 regarding time required to perform the simulations for optimizing renovation process and CT08 regarding number of adjustments to the project schedule, and ICT01 regarding reduction of the renovation process duration as well as ICT02 regarding reduction of the renovation process cost.

User Acceptance KPIs at least partially related to the DS2 are UA01 regarding productivity improvements, UA03 regarding improvements in decision making, UA05 regarding improvements in communication among peers and stakeholders, UA22 regarding level of difficulty in learning to use BIMERR tools, and UA23 regarding level of intuitiveness in user interfaces.

3.3.2.4 TEST CASE PLANNING

UC-05

Project manager selects renovation project in *Workflow modelling and simulation tool*, redesigns reference model, sets required parameters and formally verifies the model. After the verification the simulation is run, the project manager selects optimal renovation process and defines KPIs using Workflow modelling and simulation tool.

For both pilot sites, complete initial schedule will be prepared.

The Gantt chart in Fig. 3-7 illustrates the planning for DS2 UC-05 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

UC-05																	
Task	**Responsible**	**15.11.21**	**22.11.21**	**-**	**31.1.22**	**7.2.22**	**14.2.22**	**21.2.22**	**28.2.22**	**7.3.22**	**14.3.22**	**21.3.22**	**28.3.22**	**4.4.22**	**11.4.22**	**18.4.22**	**25.4.22**
Integration with the BIF	BOC																
Spanish site renovation measures ready	XYLEM+FER																
Spanish site initial schedule available	FER																
Spanish site KPIs defined	BOC+FER																
Spanish site BPMN file available	BOC																
Polish site renovation measures ready	XYLEM+BX																
Polish site initial schedule available	BX																
Polish site KPIs defined	BOC+BX																
Polish site BPMN file available	BOC																

Fig. 3-7: Gantt chart for UC-05 tasks

UC-06

Project manager creates Initial Schedule in the PWMA from imported BPMN file created in the UC-05. Project manager updates Schedule in the PWMA Execution engine and issues notification as needed.

For both pilot sites complete initial BPMN will be processed. During the demo preparation and training phase all finished tasks will be used as an example. For Spanish pilot site the tasks included in the “Main Facade and right-side lateral” group of work will be chosen (see [18] for the Spanish Gantt Chart) and detailed for demo purposes. For Polish pilot site, similar group of tasks will be chosen and elaborated into detailed workorders for approximately 2 to 3 flats.

The Gantt chart in Fig. 3-8 illustrates the planning for DS2 UC-06 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

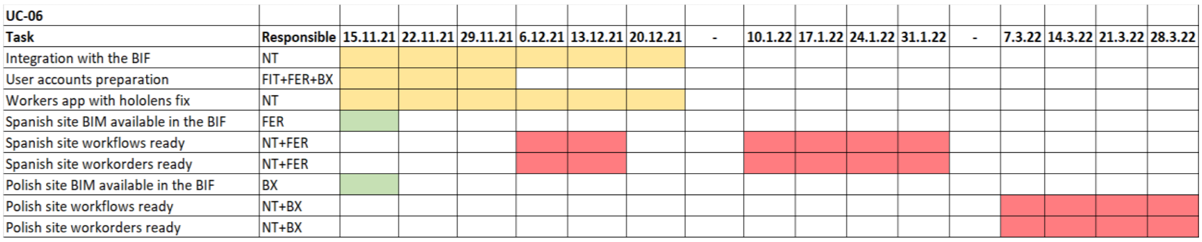


Fig. 3-8: Gantt chart for UC-06 tasks

3.4 Demo Scenario 3: based on Business Scenario 3

Demo scenario 3 is based on Business Scenario 3 and its goal is to reduce time and cost during renovation and commissioning works.

3.4.1 Tools involved

DS3 includes UC-08, UC-09 and UC-10 use cases.

UC-08 supports daily renovation activity schedules and individual guidelines provisioning to the workforce responsible through PWMA for workers and ARIBFA applications.

UC-09 supports continuous monitoring and updates of renovation activity schedules, based on reporting from the workforce and monitoring of process execution, towards effective devising and avoidance of delays using PWMA for workers and ARIBFA applications.

UC-10 supports continuous reporting from workforce and occupants for changes performed over the initial renovation design using PWMA for workers and PWMA for residents' applications.

Although not explicitly mentioned above, Adaptive Workflow Management and Automation tool, the Building Interoperability Framework (BIF), BIMERR – Management Platform (BIM-MP), and the Middleware are also involved in the demo scenarios, since these are essential for communication between tools.

3.4.2 Test cases per tool

3.4.2.1 Enablers

Each use case that will be demonstrated herein involves specific set of enablers that are summarized in Table 3-1.

Use Case	Enablers
UC-08	1. Input scheduling workorders data 2. Indoor locatlization for the user (i.e., building manager/project manager/construction manager) wearing the Hololens. This functionality is provided by the ARIBFA tool. 3. PWMA tasks should be displayed to users in from of notifications based on their current location.
UC-09	1. The workflows as prepared in the context of UC-06. 2. ARIBFA functionality to display the list of scheduled tasks to the user as they are received by the PWMA.
UC-10	1. Workorders from UC-09.

Table 3-1: Functionalities and data required for each use case of DS3

3.4.2.2 PROBABLE BLOCKERS

All three use cases involved in DS3 share the same possible blocker the incomplete integration with BIF.

3.4.2.3 KPIS ASSOCIATED WITH THE TEST CASES

Key Performance Indicators (KPIs) related to DS3 are CT40 regarding time spent for completing workflows, CT20 regarding number of workflows required for the renovation project, CT36i regarding time spend for setting up a workflow, CT25 regarding time spent for preparing the as-build project documentation, CT27 regarding time spent on scheduling/rescheduling daily activities on the construction site, CT34 regarding the time required for project rescheduling, CT35 regarding the time required for information exchange, CT38 regarding the time required to update the BIM model and ICT01 regarding reduction of the renovation process duration as well ICT02 regarding reduction of the renovation process cost.

User Acceptance KPIs at least partially related to the DS3 are UA01 regarding productivity improvements, UA03 regarding improvements in decision making, UA05 regarding improvements in communication among peers and stakeholders, UA08 regarding improvement in the perceived easiness in information exchange and tracking, UA10 regarding improvement in the perceived easiness in management of change-orders during construction phase, UA12 regarding increase in monitoring capabilities offered to stakeholders during renovation works, UA22 regarding level of difficulty in learning to use BIMERR tools, and UA23 regarding level of intuitiveness in user interfaces.

3.4.2.4 TEST CASE PLANNING

For both pilot sites the complete initial schedule will be processed. During the demo preparation and training phase all finished tasks will be used as an example. For Spanish pilot sites then tasks included in the “Main Facade and right-side lateral” group of work will be chosen and detailed for demo purposes. For Polish pilot site, similar group of tasks will be chosen and elaborated into detailed workorders for approximately 2 to 3 flats.

UC-08

With ARIBFA, the user (Building Manager/Project Manager/Construction Manager) is notified for the daily schedules in the context of workflows that are assigned to working crews around the construction site considering the user’s location. The pipeline for receiving the daily schedules and assigned tasks in the ARIBFA tool is displayed in Fig. 3-9. More specifically, the user is notified for the list of tasks that coincide with the calculated location that they are currently in (specific IfcSpace). In detail, the flow of the test case for the ARIBFA tool is:

- The user logs into the ARIBFA application using their credentials.
- ARIBFA receives scheduled tasks from PWMA through BIF.
- ARIBFA uses indoor localization to find the user’s position in the building.
- Based on their location (IfcSpace), ARIBFA notifies the user for the scheduled tasks that are related to the specific IfcSpace.
- By pressing the notification button, the scheduled tasks are displayed in an AR menu.

Fig. 3-9: The pipeline with which ARIBFA receives the workflows and tasks in order to display them and notify the user

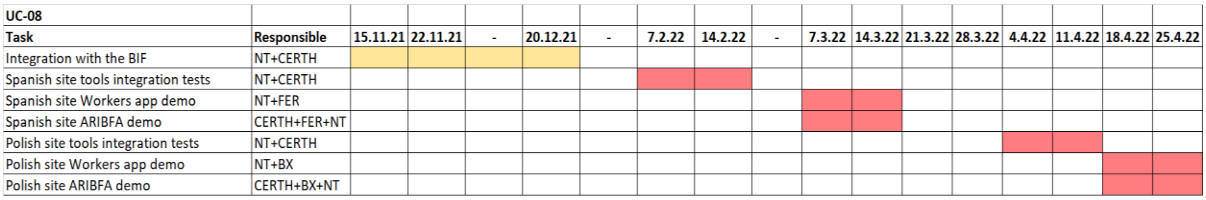


Fig. 3-10: Gantt chart for UC-08 tasks

UC-09

Site manager selects reconstruction task and develops corresponding work orders and work instructions in the PWMA Execution engine UI. Site manager assigns Work orders to Worker. Worker reports results of Work order to Site manager.

The Gantt chart in Fig. 3-11 illustrates the planning for DS3 UC-09 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

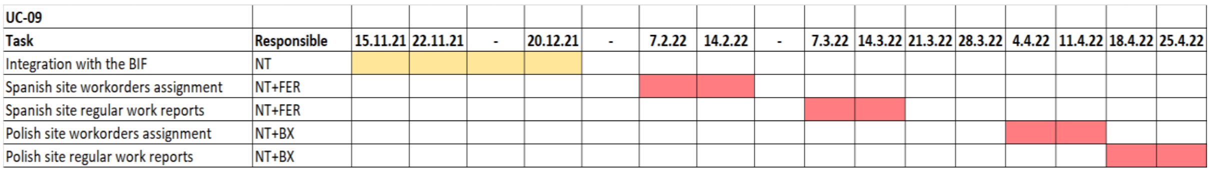


Fig. 3-11: Gantt chart for UC-09 tasks

UC-10

Foreman/worker sends change notification to the Site manager. Notification is in the form of a text message and photo can be included as well. Site manager verifies the change and decides whether to adjust respective workorder or the change request should be ignored, then send a notification to Foreman.

With PWMA for residents, the user (resident) sends changes notifications about the related tasks that are displayed on the main screen. In detail, the flow of the test case for the PWMA for residents' application is:

- The user logs into the PWMA for residents' application using their credentials.
- PWMA for residents receives scheduled tasks from PWMA through BIF.
- The user taps on a specific task to see additional details and he will be directed to the Task Details screen.
- The user comments on the task writing a text, taking a photograph or a video or even making a recording.

The Gantt chart in Fig. 3-12 illustrates the planning for DS3 UC-10 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

UC-10																	
Task	Responsible	15.11.21	22.11.21	-	20.12.21	-	7.2.22	14.2.22	-	7.3.22	14.3.22	21.3.22	28.3.22	4.4.22	11.4.22	18.4.22	25.4.22
Integration with the BIF	NT																
Spanish site worker notification tests	NT+FER																
Spanish site residents notification tests	CERTH+FER																
Spanish site worker notification demo	NT+FER																
Spanish site residents notification demo	CERTH+FER																
Polish site worker notification tests	NT+BX																
Polish site residents notification tests	CERTH+BX																
Polish site worker notification demo	NT+BX																
Polish site residents notification demo	CERTH+BX																

Fig. 3-12: Gantt chart for UC-10 tasks

3.5 Demo Scenario 4: based on Business Scenario 4

Demo Scenario 4 (DS4) is based on Business Scenario 4 and its goal is to assist in increasing workforce and occupants' safety during renovation works.

The two main functionalities that will be demonstrated in this scenario are depicted in Fig. 3-13 and

Fig. 3-14.

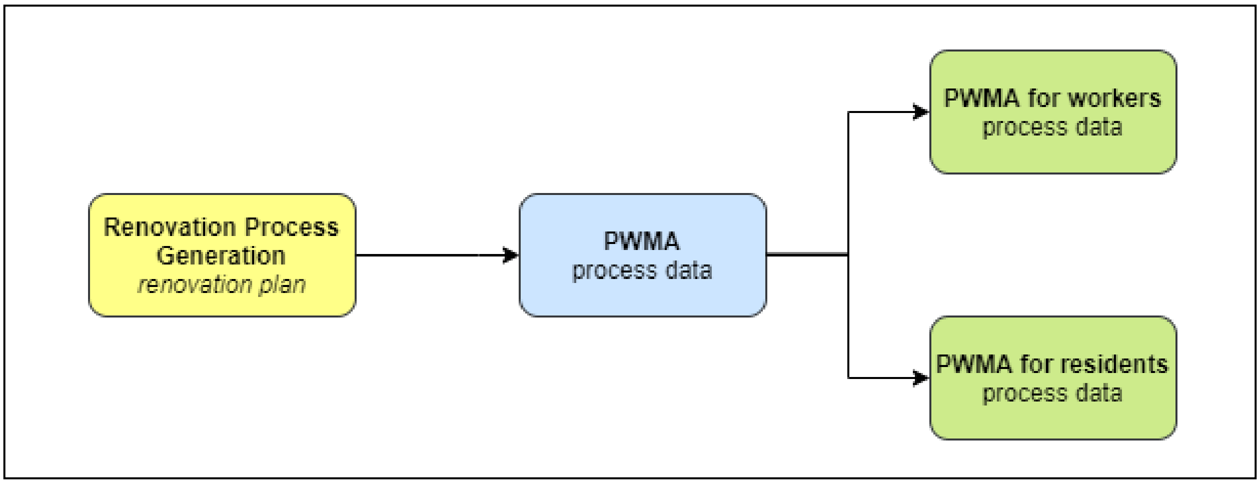


Fig. 3-13: Residents receive tasks data and H&S notifications:

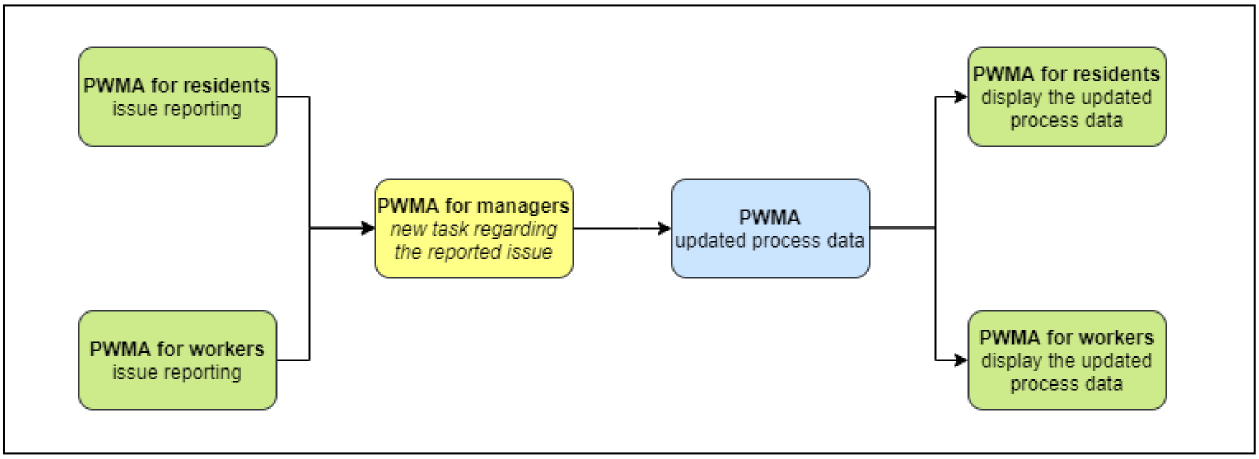


Fig. 3-14: Residents report an issue:

3.5.1 Tools involved

DS4 includes several use cases, namely UC-05, UC-06, UC-10, UC-11 and UC-12. As detailed in the following, each UC has a particular aim and involves diverse tools.

UC-05 is connected to the generation of the accurate scheduling of the renovation's activities by PWMA.

UC-06 includes the rescheduled tasks aiming to ensure the efficiency of renovation project implementation processes and involves PWMA.

UC-10 relates to workers and residents to report changes in the renovation project during the construction and involves PWMA for residents, PWMA for workers and PWMA.

UC-11 includes the display of health and safety instructions for workers and residents by site manager and involves PWMA, PWMA for residents, PWMA for workers.

UC-12 relates to the continuous reporting from workforce and residents for threats and dangers and the corresponding automated update of the BIM model and involves PWMA for residents, PWMA for workers and PWMA.

Although not explicitly mentioned above, the Building Interoperability Framework (BIF), and the Middleware are also involved in the demo scenario, since these are essential for communication between tools

3.5.2 Test cases per tool

3.5.2.1 Enablers

Each use case that will be demonstrated herein involves specific set of enablers that are summarized in Table 3-2.

Use Case	Enablers
UC-05	1. Input scheduling workorders data
UC-06	1. Rescheduling workorders data in the PWMA 2. Output rescheduling workorders data to the workers and residents 3. Communication between the PWMA for residents with PWMA (through BIF) 4. Communication between PWMA for workers and PWMA (directly).
UC-010	1. Input data: reported changes from residents and workers 2. Communication between the PWMA for residents with PWMA (through BIF) 3. Communication between PWMA for workers and PWMA (directly)
UC-11	1. Input data: health and safety instructions to residents and workers 2. Communication between the PWMA for residents with PWMA (through BIF) 3. Communication between PWMA for workers and PWMA (directly)
UC-12	1. Input data: reported issues from residents and workers to the site manager 2. Communication between the PWMA for residents with PWMA (through BIF) 3. Communication between the PWMA for workers and PWMA (directly)

Table 3-2: Functionalities and data required for each use case of DS4

3.5.2.2 Probable Blockers

Regarding DS4 blockers, UC-05 has no blockers while UC-06, UC-10-UC-12 share the same blocker which is the incomplete integration with the BIF.

3.5.2.3 KPIs Associated with the Test Cases

Several KPIs are related to DS4. CT10, which measures the time for uploading data to the BIF, is associated with all the related UCs; In UC-05, UC-06 and UC-10 User Acceptance (UA) KPI productivity improvement (UA1) is measured. UA2 (efficiency of task completion) is measured both in UC-06 and UC-10.

UA16 (improvement in perceived safety at construction site), UA22 (level of difficulty in learning to use BIMERR tools) and UA23 (level of intuitiveness in user interfaces) are measured in UC-10, UC -11 and UC-12. Both UA17 (Improved safety communications in the construction site) and UA18 (Working crews' level of satisfaction with management commitment to H&S) are measured in UC-11 and UC-12.

3.5.2.4 Test Case Planning

For both pilot sites complete initial schedule will be processed. During the demo preparation and training phase all finished tasks will be used as an example.

UC-05-PWMA

Project manager selects renovation project in Workflow modelling and simulation tool, redesigns reference model, sets required parameters and formally verifies the model. After the verification the simulation is run, the project manager selects optimal renovation process and defines KPIs using Workflow modelling and simulation tool.

For both pilot sites, complete initial schedule will be prepared.

The Gantt chart in Fig. 3-15 illustrates the planning for DS4 UC-05 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

UC-05																	
Task	**Responsible**	**15.11.21**	**22.11.21**	**-**	**31.1.22**	**7.2.22**	**14.2.22**	**21.2.22**	**28.2.22**	**7.3.22**	**14.3.22**	**21.3.22**	**28.3.22**	**4.4.22**	**11.4.22**	**18.4.22**	**25.4.22**
Integration with the BIF	BOC																
Spanish site renovation measures ready	XYLEM+FER																
Spanish site initial schedule available	FER																
Spanish site KPIs defined	BOC+FER																
Spanish site BPMN file available	BOC																
Polish site renovation measures ready	XYLEM+BX																
Polish site initial schedule available	BX																
Polish site KPIs defined	BOC+BX																
Polish site BPMN file available	BOC																

Fig. 3-15: Gantt chart for UC-05 tasks

UC-06 PWMA

Project manager creates Initial Schedule in the PWMA from imported BPMN file created in the UC-05. Project manager updates Schedule in the PWMA Execution engine and issues notification as needed.

For both pilot sites complete initial BPMN will be processed. During the demo preparation and training phase all finished tasks will be used as an example. For Spanish pilot sites then tasks included in the "Main Facade and right-side lateral" group of work will be chosen and detailed for demo purposes. For Polish pilot site, similar group of tasks will be chosen and elaborated into detailed workorders for approximately 2 to 3 flats.

The Gantt chart in Fig. 3-16 illustrates the planning for DS4 UC-06 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

UC-06																	
Task	**Responsible**	**15.11.21**	**22.11.21**	**29.11.21**	**6.12.21**	**13.12.21**	**20.12.21**	**-**	**10.1.22**	**17.1.22**	**24.1.22**	**31.1.22**	**-**	**7.3.22**	**14.3.22**	**21.3.22**	**28.3.22**
Integration with the BIF	NT																
User accounts preparation	FIT+FER+BX																
Workers app with hololens fix	NT																
Spanish site BIM available in the BIF	FER																
Spanish site workflows ready	NT+FER																
Spanish site workorders ready	NT+FER																
Polish site BIM available in the BIF	BX																
Polish site workflows ready	NT+BX																
Polish site workorders ready	NT+BX																

Fig. 3-16: Gantt chart for UC-06 tasks

UC-10-PWMA, PWMA for workers and PWMA for residents

Foreman/worker sends change notification using PWMA for workers to the Site manager. Notification is in the form of a text message and photo can be included as well. Site manager verifies the change and decides whether to adjust respective workorder or the change request should be ignored, then send a notification to Foreman.

The Gantt chart in Fig. 3-17 illustrates the planning for DS4 UC-10 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

With PWMA for residents, the user (resident) sends changes notifications about the related tasks that are displayed on the main screen. In detail, the flow of the test case for the PWMA for residents' application is:

- The user logs into the PWMA for residents' application using their credentials.
- PWMA for residents receives scheduled tasks from PWMA through BIF.
- The user taps on a specific task to see additional details and he will be directed to the Task Details screen.
- The user comment on the task writing a text, taking a photograph or a video or even making a recording.

UC-10																	
Task	**Responsible**	**15.11.21**	**22.11.21**	**-**	**20.12.21**	**-**	**7.2.22**	**14.2.22**	**-**	**7.3.22**	**14.3.22**	**21.3.22**	**28.3.22**	**4.4.22**	**11.4.22**	**18.4.22**	**25.4.22**
Integration with the BIF	NT																
Spanish site worker notification tests	NT+FER																
Spanish site residents notification tests	CERTH+FER																
Spanish site worker notification demo	NT+FER																
Spanish site residents notification demo	CERTH+FER																
Polish site worker notification tests	NT+BX																
Polish site residents notification tests	CERTH+BX																
Polish site worker notification demo	NT+BX																
Polish site residents notification demo	CERTH+BX																

Fig. 3-17: Gantt chart for UC-10 tasks

UC-11-PWMA, PWMA for workers and PWMA for residents

H&S manager attaches H&S instructions and report in form of documents or photos, updates Schedule in the PWMA Execution engine and issues respective notifications as needed. Forman/worker reads the instructions using PWMA for workers.

The Gantt chart in Fig. 3-18 illustrates the planning for DS4 UC-11 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

With PWMA for residents, the user (resident) receives H&S notifications about the related tasks that are displayed on the main screen. Additionally, the user can see all the notifications in the "Notifications" tab. In detail, the flow of the test case for the PWMA for residents' application is:

- The user opens the PWMA for residents' application.
- PWMA for residents receives scheduled tasks from PWMA through BIF with H&S annotations for each task.

- The user taps on "Notifications" tab to be navigated to the "Notifications" screen to see all the related H&S notifications.

UC-11																	
Task	Responsible	15.11.21	22.11.21	-	20.12.21	-	7.2.22	14.2.22	-	7.3.22	14.3.22	21.3.22	28.3.22	4.4.22	11.4.22	18.4.22	25.4.22
Integration with the BIF	NT																
Spanish site worker H&S instructions tests	NT+FER																
Spanish site residents H&S instructions tests	CERTH+FER																
Spanish site worker H&S instructions demo	NT+FER																
Spanish site residents H&S instructions demo	CERTH+FER																
Polish site worker H&S instructions tests	NT+BX																
Polish site residents H&S instructions tests	CERTH+BX																
Polish site worker H&S instructions demo	NT+BX																
Polish site residents H&S instructions demo	CERTH+BX																

Fig. 3-18: Gantt chart for UC-11 tasks

UC-12-PWMA and PWMA for workers

Foreman/worker sends H&S issue using PWMA for workers to the Site manager. Issues in the form of a text message and photo can be included as well. Site manager verifies the issue and decides whether to adjust respective workorder or the issue should be ignored, then send a notification to Foreman.

The Gantt chart in Fig. 3-19 illustrates the planning for DS4 UC-12 activities. Already completed tasks are depicted in green, ongoing activities are depicted in yellow, and pending tasks are depicted in red.

With PWMA for residents, the user (resident) submits potential issues he encounters in the building and makes suggestions by completing a form with photographs, videos and text or voice description, at any time. In detail, the flow of the test case for the PWMA for residents' application is:

- The user opens the PWMA for residents' application.
- The user taps on "New Issue" tab to be navigated to the "New Issue" screen to start reporting the issue.
- In the first stage he/she confirms their location.
- In the second stage he/she selects the type of the issue that he/she encounters.
- In the third stage he/she adds a title and a description that consists of a text with a voice message or/and adding a photo or video.

UC-12																	
Task	Responsible	15.11.21	22.11.21	-	20.12.21	-	7.2.22	14.2.22	-	7.3.22	14.3.22	21.3.22	28.3.22	4.4.22	11.4.22	18.4.22	25.4.22
Integration with the BIF	NT																
Spanish site worker H&S issues tests	NT+FER																
Spanish site residents H&S issues tests	CERTH+FER																
Spanish site worker H&S issues demo	NT+FER																
Spanish site residents H&S issues demo	CERTH+FER																
Polish site worker H&S issues tests	NT+BX																
Polish site residents H&S issues tests	CERTH+BX																
Polish site worker H&S issues demo	NT+BX																
Polish site residents H&S issues demo	CERTH+BX																

Fig. 3-19: Gantt chart for UC-12 tasks

3.6 Demo Scenario 5: based on Business Scenario 5

In alignment with Business Scenario 5, as it has been documented in D3.1, Demo Scenario 5 (DS5) aims to support AEC stakeholders on accurately predicting the energy performance of a building, subject to an energy renovation. To this direction, the establishment of an accurate calculation methodology of Energy, Urban, Comfort and LCC/LCA KPIs, as they are described in Section 2.3, is implied. Such KPIs must be calculated for the baseline scenario that reflects the current status of the building before being renovated, and for each candidate renovation scenario, allowing to estimate the impact of combinations of energy conservation without being applied in reality.

Towards increasing the accuracy of the calculated KPIs, the use of IoT metering and sensing data is twofold: (1) to learn how occupants behave and interact with the energy systems of the buildings and generate profiles that mimic their actions upon them; and (2) to calibrate the baseline building energy performance models following the option D of IPMVP, as it has been described in Section 1.2.6.7.

This section introduces the BIMERR components that are deployed, enablers and potential blockers that are identified, KPIs that are considered, and a test case plan in both pilot sites that is drafted for the realisation of DS5.

3.6.1 Tools involved

The BIMERR components that are involved in DS5 are the following: (1) RenoDSS, (2) PRUBS, (2) Middleware, (3) BIF, and (4) Material and components database.

RenoDSS is the web application that provides to the renovation designer an accurate estimation of the Energy, Cost, Life Cycle Assessment trade-offs of various alternative renovation scenarios, based on the available renovation options in terms of materials and components. To deliver its scope, RenoDSS requires as input (1) an IFC file, enriched with second level space boundaries information, and (2) an obXML file that capture the static and dynamic data, respectively, for a specific project. Renovation scenarios are set by extracting relevant information from the material and components database.

PRUBS is the "as-is" building information extraction and model population tool that is responsible for providing dynamic data that is required for the energy KPIs calculation. Dynamic data refers to trained occupant behavior models that are delivered in an obXML format file.

For the occupant behavior models training, IoT data streams are requested and acquired by the Middleware endpoints provided for each site.

There is no direct communication between the RenoDSS and PRUBS. To access the populated obXML file for each project (pilot site), RenoDSS interacts with BIF, RenoDSS receives these models from BIF, that in turn forwards them to its Building Energy Performance (BEP) modelling component to compute the Energy KPIs. The same holds for the IFC file retrieval.

3.6.2 Enablers

DS5 is linked with six use cases, as they have been identified in the context of T3.1 and are listed below.

UC-03, with title "Adapt design to the actual building use, including accurate information about occupancy and schedules, comfort, requirements/ preferences and energy uses" aims to generate the as-is occupant behavior data that pertain to the user thermal comfort zones and energy systems usage profiles' definition. As mentioned above, to extract such information, IoT data received from the Middleware is used. Thus, enablers for this use case demonstration are (1) IoT data of high quality for a long period to consider the seasonality impact on the trained models, and (2) inclusion of ifcZones and IfcSpaces ids in the static configuration of the WSN (received from Middleware) to perform the linkage between the static (IFC) and dynamic (obXML) data. Note here that the obXML file is generated automatically, hence, there is no need for stakeholders' participation in the demonstration activities. However, occupants' feedback to trained models is received implicitly through BICA, where occupants are allowed to report their thermal comfort preferences.

UC-04 involves any action relevant to the materials and components database population with data that pertain to the as-is and as-renovated construction (material layers bedding) and energy systems' characteristics. Enabler for this use case is a material and components database that is easily extensible to capture the as-is and the candidate renovation measures material and components data. Stakeholders that are engaged in UC-04 are the users of RenoDSS (e.g., Energy Auditor, Architect or Renovation Planner), who ensure that the as-is building and candidate renovation measures information is available in the material and components database. If missing data is identified, the user should add it manually but effortlessly through RenoDSS UI.

UC-13 to UC-16 aim to demonstrate RenoDSS capability to evaluate candidate renovation scenarios' performance, expressed by calculated Energy, LCC-LCA, Comfort and Urban KPIs. For the evaluation of each scenario, RenoDSS invokes its modules to conduct the respective simulations. Having as input the IFC file that corresponds to a specific scenario, and the baseline obXML and EPW files, RenoDSS-BEP calculates the Energy and Comfort KPIs. RenoDSS-LCC-LCA computes the LCC-LCA based on data extracted from the IFC file.

Common enabler for these UCs demonstration is a complete, consistent, and correct IFC file as resulted from UC-01, UC-02 and a rich material and components database as resulted from UC-04. Furthermore, in UC-13 and UC-15, (1) a complete, consistent, and correct obXML file, output of UC-03, and (2) an EPW file that provides the climate data of the building's location for a typical meteorological year (TMY) is required.

Stakeholders to be involved in the UC-13 to UC-15 demonstration activities are persons that have been involved in the energy audit and renovation study in both pilot sites.

3.6.3 Probable Blockers

In UC-03, identified issues with the firmware of Fibaro HCL resulted to missing IoT data for a long period that affected the occupant behavior models training. Although they have been resolved, similar issues may raise that will affect the quality of IoT data and the trained occupant behavior models consequentially. For this potential risk, mitigation measures have already been considered. For each building, the output of PRUBS (obXML) is automatically initialised with a combination of thermal comfort bounds, artificial lighting, and electric equipment usage, extracted from standards (e.g., ASHRAE 55, ISO7730) and relevant information provided by the BIM model (relevant guidelines have been provided to include such data in Revit). Whenever meaningful IoT data that represent a season is available (e.g. when RMSE < 10%), the trained models replace the relevant objects of the populated obXML.

In the context of T8.1 activities, a significant effort has been made to populate the material and components database with data that reflect the current status of both pilot sites and energy conservation measures that are going to be applied in reality. In the Spanish building, the actual renovation works have started, and the actual renovation scenario has been well documented. In the Polish building, the public tender for the renovation project has not been finished yet, therefore concrete information for the renovation measures that are going to be applied is not available. Such missing information may be considered as a potential blocker for UC-04 demonstration in the Polish building. However, T8.1 has managed to populate the material and component database with potential renovation materials.

In UC-13 to UC-16, incomplete, incorrect, or inconsistent IFC files resulted from UC-01 and UC-02 may have significant impact on demonstration activities. To mitigate this risk, IFC files are exported from BIM models that has been designed in Revit. BIM-Design-Guidelines, Revit Families and a modified Revit IFC exporter have been provided by the consortium to ensure that all the necessary information is captured in the exported IFC files.

3.6.4 *KPIs Associated with the Test Cases*

All the KPIs that are described in Section 2.3, along with “CT41 – Time required to complete the as-is Building Energy Performance model design” and “CT42 – Time required to perform the candidate renovation scenarios' evaluation”, are considered within DS5.

3.6.5 *Test Case Planning*

Since RenoDSS and PRUBS execution neither depends on the actual renovation works, nor affects the demonstration of other BIMERR tools, the tasks of DS5 could run for both pilot sites, ideally when the obXML and IFC files would be complete, and the actual renovation measures would be known for each pilot site. However, we decided to introduce three-rounds of demos/tests, relevant to DS5, as detailed below.

Round 1 - Using the almost complete versions of IFCs and obXMLs populated based on standards, we initially run some experiments internally due **15/12/2021**. Scope of this exercise is to make sure that future end-users will not experience any problem. In parallel, relevant stakeholders are being trained using as examples the pre-validation sites.

Round 2 - With a complete and correct IFC file at hand and having collected enough IoT data, the occupant behavior models are trained and update the obXML file due **15/03/2022**. Simulations run again through RenoDSS to showcase the impact of IoT data-driven dynamic profiles on the energy performance estimation of a building.

Round 3 – Additional IoT data is being received, increasing the prediction accuracy of the occupant behavior models due **30/04/2022**. In parallel, we expect that information about the actual renovation measures to be applied in the Polish building will become available due **30/03/2022**. Simulations of baseline and renovation scenarios through RenoDSS is repeated due **30/04/2022**.

The three-rounds of experiments are reflected in the UC-03, UC-04 and UC-13-16 tasks’ planning, depicted in Fig. 3-20, Fig. 3-21 and Fig. 3-22, respectively.

UC-03														
Task		**Responsible**	**15/11/21**	**30/11/21**	**15/12/21**	**30/12/21**	**15/1/22**	**30/1/22**	**15/2/22**	**28/2/22**	**15/3/22**	**30/3/22**	**15/4/22**	**30/4/22**
Common	PRUBS Integration with Keycloak	Hypertech-FIT												
	PRUBS Integration with BIF	Hypertech-Suite5												
	PRUBS data collection job update in BIF	Hypertech-Suite5												
Spanish building	Complete version of IFC available	FER-UCL												
	Middlware WoT population with IfcZone and IfcSpace GUIDs	FIT												
	obXML population with data extracted from standards - v1	Hypertech												
	obXML data update - v2	Hypertech												
	obXML data update - v3	Hypertech												
Polish building	Complete version of IFC available	BX-UCL												
	Middlware WoT population with IfcZone and IfcSpace GUIDs	FIT												
	obXML population with data extracted from standards - v1	Hypertech												
	obXML data update - v2	Hypertech												
	obXML data update - v3	Hypertech												

Fig. 3-20: UC-03 Gantt chart – completed (green), in-progress (yellow) and not-started-yet (red) tasks

UC-04														
Task		**Responsible**	**15/11/21**	**30/11/21**	**15/12/21**	**30/12/21**	**15/1/22**	**30/1/22**	**15/2/22**	**28/2/22**	**15/3/22**	**30/3/22**	**15/4/22**	**30/4/22**
Spanish building	Complete version of IFC available	FER-UCL												
	Material and components database populated with baseline data	XYLEM-FER												
	Material and components database populated with actual renovation data	XYLEM-FER												
Polish building	Complete version of IFC available	BX-UCL												
	Material and components database populated with baseline data	XYLEM-BX												
	Material and components database populated with candidate renovation data	XYLEM-BX												
	Material and components database populated with actual renovation data	XYLEM-BX												

Fig. 3-21: UC-04 Gantt chart – completed (green), in-progress (yellow) and not-started-yet (red) tasks

UC-13-16														
Task		**Responsible**	**15/11/21**	**30/11/21**	**15/12/21**	**30/12/21**	**15/1/22**	**30/1/22**	**15/2/22**	**28/2/22**	**15/3/22**	**30/3/22**	**15/4/22**	**30/4/22**
Common	RenoDSS Integration with Keycloak	XYLEM-FIT												
	RenoDSS Integration with BIF	XYLEM-Suite5												
	Material and components database populated with baseline data	XYLEM-FER-BX												
Spanish building	Complete version of IFC available	FER-UCL												
	Material and components database populated with actual renovation data	XYLEM-FER												
	obXML population with data extracted from standards - v1	Hypertech												
	Renovation scenarios simulation - v1	XYLEM-Hypertech												
	obXML data update - v2	Hypertech												
	Renovation scenarios simulation - v2	XYLEM-Hypertech												
	obXML data update - v3	Hypertech												
	Renovation scenarios simulation - v3	XYLEM-Hypertech												
Polish building	Complete version of IFC available	BX-UCL												
	Material and components database populated with actual renovation data	XYLEM-BX												
	obXML population with data extracted from standards - v1	Hypertech												
	Renovation scenarios simulation - v1	XYLEM-Hypertech												
	obXML data update - v2	Hypertech												
	Renovation scenarios simulation - v2	XYLEM-Hypertech												
	obXML data update - v3	Hypertech												
	Renovation scenarios simulation - v3	XYLEM-Hypertech												

Fig. 3-22: UC-13, 14, 15 and 16 Gantt chart – completed (green), in-progress (yellow) and not-started-yet (red) tasks

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ANNEX I. POLISH PILOT BUILDING: INTERNAL GAINS BY ARTIFICIAL LIGHTING AND ELECTRICAL EQUIPMENT

Internal Gains					
		Artificial Lighting data		Electric Equipment data	
		Specified Lighting Load / Lighting bulbs/tubes Power	Specified Lighting Load per area/Artificial lighting gains (W/m2)	Specified Power Load/Electric Equipment Power	Specified Power Load per area/Electric Equipment gains (W/m2)
Staircase 1					
Level 1					
Apartment nr.1					
Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
Apartment nr.2					
Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 1,5					
Apartment nr.3					
Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
Apartment nr.4					
Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2					
Apartment nr.6					
Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²

		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.7						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2,5							
	Apartment nr.8						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.9						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3							
	Apartment nr.10						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.11						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3,5							
	Apartment nr.12						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.13						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²

		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 4							
	Apartment nr.14						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.15						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Staircase 2							
Level 1							
	Apartment nr.16						
			3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.17						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 1,5							
	Apartment nr.18						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.19						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²

		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2							
	Apartment nr.20						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.21						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2,5							
	Apartment nr.22						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.23						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3							
	Apartment nr.24						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.25						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3,5							
	Apartment nr.26						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²

		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.27						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 4							
	Apartment nr.28						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.29						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Staircase 3							
Level 1							
	Apartment nr.30						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.31						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 1,5							
	Apartment nr.32						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²

	Apartment nr.33						
		Corridor	8,61 m^2	83 W	9.69 W/m^2	50 W	5.81 W/m^2
		Living Room	17 m^2	165 W	9.69 W/m^2	99 W	5.81 W/m^2
		Bedroom	11,7 m^2	113 W	9.69 W/m^2	68 W	5.81 W/m^2
		Bathroom	4,18 m^2	41 W	9.69 W/m^2	24 W	5.81 W/m^2
		Kitchen	5,85 m^2	57 W	9.69 W/m^2	34 W	5.81 W/m^2
Level 2							
	Apartment nr.34						
		Corridor	3,78 m^2	37 W	9.69 W/m^2	22 W	5.81 W/m^2
		Living Room	15,57 m^2	145 W	9.69 W/m^2	90 W	5.81 W/m^2
		Bedroom	7,54 m^2	73 W	9.69 W/m^2	44 W	5.81 W/m^2
		Bathroom	4,69 m^2	45 W	9.69 W/m^2	27 W	5.81 W/m^2
		Kitchen	5,02 m^2	49 W	9.69 W/m^2	29 W	5.81 W/m^2
	Apartment nr.35						
		Corridor	8,61 m^2	83 W	9.69 W/m^2	50 W	5.81 W/m^2
		Living Room	17 m^2	165 W	9.69 W/m^2	99 W	5.81 W/m^2
		Bedroom	11,7 m^2	113 W	9.69 W/m^2	68 W	5.81 W/m^2
		Bathroom	4,18 m^2	41 W	9.69 W/m^2	24 W	5.81 W/m^2
		Kitchen	5,85 m^2	57 W	9.69 W/m^2	34 W	5.81 W/m^2
Level 2,5							
	Apartment nr.36						
		Corridor	3,78 m^2	37 W	9.69 W/m^2	22 W	5.81 W/m^2
		Living Room	15,57 m^2	145 W	9.69 W/m^2	90 W	5.81 W/m^2
		Bedroom	7,54 m^2	73 W	9.69 W/m^2	44 W	5.81 W/m^2
		Bathroom	4,69 m^2	45 W	9.69 W/m^2	27 W	5.81 W/m^2
		Kitchen	5,02 m^2	49 W	9.69 W/m^2	29 W	5.81 W/m^2
	Apartment nr.37						
		Corridor	8,61 m^2	83 W	9.69 W/m^2	50 W	5.81 W/m^2
		Living Room	17 m^2	165 W	9.69 W/m^2	99 W	5.81 W/m^2
		Bedroom	11,7 m^2	113 W	9.69 W/m^2	68 W	5.81 W/m^2
		Bathroom	4,18 m^2	41 W	9.69 W/m^2	24 W	5.81 W/m^2
		Kitchen	5,85 m^2	57 W	9.69 W/m^2	34 W	5.81 W/m^2
Level 3							
	Apartment nr.38						
		Corridor	3,78 m^2	37 W	9.69 W/m^2	22 W	5.81 W/m^2
		Living Room	15,57 m^2	145 W	9.69 W/m^2	90 W	5.81 W/m^2
		Bedroom	7,54 m^2	73 W	9.69 W/m^2	44 W	5.81 W/m^2
		Bathroom	4,69 m^2	45 W	9.69 W/m^2	27 W	5.81 W/m^2
		Kitchen	5,02 m^2	49 W	9.69 W/m^2	29 W	5.81 W/m^2
	Apartment nr.39						
		Corridor	8,61 m^2	83 W	9.69 W/m^2	50 W	5.81 W/m^2
		Living Room	17 m^2	165 W	9.69 W/m^2	99 W	5.81 W/m^2
		Bedroom	11,7 m^2	113 W	9.69 W/m^2	68 W	5.81 W/m^2
		Bathroom	4,18 m^2	41 W	9.69 W/m^2	24 W	5.81 W/m^2

		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3,5							
	Apartment nr.40						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.41						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 4							
	Apartment nr.42						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.43						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Staircase 4							
Level 1							
	Apartment nr.44						
			3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.45						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 1,5							
	Apartment nr.46						

		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.47						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2							
	Apartment nr.48						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.49						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 2,5							
	Apartment nr.50						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.51						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3							
	Apartment nr.52						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²

	Apartment nr.53						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 3,5							
	Apartment nr.54						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.55						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 4							
	Apartment nr.56						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.57						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²
		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²
Level 4,5							
	Apartment nr.58						
		Corridor	3,78 m²	37 W	9.69 W/m²	22 W	5.81 W/m²
		Living Room	15,57 m²	145 W	9.69 W/m²	90 W	5.81 W/m²
		Bedroom	7,54 m²	73 W	9.69 W/m²	44 W	5.81 W/m²
		Bathroom	4,69 m²	45 W	9.69 W/m²	27 W	5.81 W/m²
		Kitchen	5,02 m²	49 W	9.69 W/m²	29 W	5.81 W/m²
	Apartment nr.59						
		Corridor	8,61 m²	83 W	9.69 W/m²	50 W	5.81 W/m²
		Living Room	17 m²	165 W	9.69 W/m²	99 W	5.81 W/m²
		Bedroom	11,7 m²	113 W	9.69 W/m²	68 W	5.81 W/m²
		Bathroom	4,18 m²	41 W	9.69 W/m²	24 W	5.81 W/m²

		Kitchen	5,85 m²	57 W	9.69 W/m²	34 W	5.81 W/m²