BIM4EEB

BIM based fast toolkit for
Efficient rEnovation in Buildings

D8.2 Report on demonstration in Italy

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D8.2 Report on demonstration in Italy

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EXECUTIVE SUMMARY

This document describes the demonstration of a BIM-based fast toolkit for Efficient rEnovation of residential Buildings on the Italian demonstration site in the city of Monza. The project demosite consists in a social housing multistorey building built at the beginning of 1980's.

At the Italian demosite the entire toolkit developed within the project was tested. The BIM Management System (BIMMS) was demonstrated as the common data environment for the project storing BIM models of the building, documents, sensors streaming, activities done at site, alerts and preferences of the inhabitants. Fast Mapping tool demonstrated the capabilities of the devices developed for mapping and scanning the built environment. BIMeaser simulated with great accuracy the energy performance of the existing, and of the renovated building. BIM4Occupants gave both the inhabitants and the owner the possibility to monitor the Indoor Environmental Quality of the apartments, such as an up to date information about the renovation works and the possibility to rise alerts. BIMPlanner was used to monitor the activities at site using BIM based location breakdown structure. The tool, along with BIMMS and BIM4Occupants, demonstrated for sample apartments an occupant-centric approach for participative renovation planning. BIMcpd provided the building owner with the possibility to evaluate and monitor effectively the indoor performance of the renovated spaces. The report contains a description of the pilot site and minor changes in apartments selection and sensors choices that have been occurred respect to D8.1 Report on management of real Best Practice Examples. Sensors' set up has been outlined highlighting the position within the flats and the reason for the choice. The demonstration activity started with nine occupants involved (namely nine apartments) but it ended with the involvement of thirteen of them. Four new families have decided to join the project after successful demonstration workshops and engagement activities. Based on the D3.5 Measurement and Verification protocol, the Key Performance Indicators (KPIs) have been considered as a method to assess the success of the project. The analysis of their calculation has been studied such as the baseline definition for some of them. They have two different subdivisions: from one side, they have been grouped into primary and secondary KPIs, on the other side, they have been categorized according to the different topics they represent. Some relevant results related to the first group of KPI reveals that: the primary energy saving due to the renovation was equal to 38%, such as the renovation time and costs were more than 28 and 20%,compared to a standard baseline of times and costs for similar Italian renovation projects. In addition, occupancy of the apartments was obtained with a 90% accuracy.

PUBLISHING SUMMARY

The following document presents the work carried out for the demonstration activity of the BIM-based toolkit on the Italian pilot site. The Italian demonstration site has been chosen as a good example of a residential building in the Mediterranean climate zone and, since it is social housing building the significance of a more fragile part of the population has been taken into account. The demonstration activity started with 9 families involved (namely 9 apartments) but it ended with the involvement of 13 apartments, as 4 new families decided to join the project after the workshops (which is a good result in itself).

For the Italian demonstration site, the whole toolkit has been demonstrated. Therefore, it is possible to have a more complete view of the project. The report presents the obtained results of the project and the application of the developed toolkit, whose success has been assessed by the use of different Key Performance Indicators. Description of the several workshops held and the analysis of the baseline necessary for the assessment of the indicators are also present in the document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

This document aims at presenting a demonstration of the BIM-based toolkit developed in the BIM4EEB project and the application to a public residential building subject to renovation interventions during the demonstration and validation period of the project. The building has the architectural typology and construction technology typical of Italian public housing from the 70s/80s; moreover, due to its location in the Lombardy region (Italy), it is a representative example of climatic conditions characterising South Europe.

In the Italian demonstration site, the whole BIM-based toolkit has been tested. This allowed to have a clear overview of: the BIM-assisted Energy refurbishment assessment tool (BIMeaser), the surveying of the existing building (Fast Mapping Toolkit), the monitoring and construction management of the renovation project (BIMPlanner), the updated feedback of the building status and renovation activities (BIM4Occupants), and constraint checking, performance evaluation and data management tool (BIMcpd), Room Automation Systems designing (AUTERAS), and the collection and storage of information and data within the BIM Management System (BIMMS).

The report is composed of a first part, Chapter 2, which describes the Italian demonstration site, the main ongoing renovation activities and the sensors set up and related changes that occurred with respect to what is stated in D 8.1. Chapter 3 illustrates the demonstration process activity performed for each tool. Chapter 4 and 5 focus respectively on the primary and secondary KPIs assessment. Finally, Chapter 6 contains the conclusions of the report and the main lessons learnt.

1.1 Relation to other work in BIM4EEB

This document shows the practical elaboration of the analysis and studies about the BIM-based toolkit developed during the project. Since several documents are connected to it, many references can be identified:

For BIMMS:

- D4.9 Tested version of the platform (public report) [BIM4EEB, 2021a]
- D4.10 Testing and validation results on demonstration sites (public report) [BIM4EEB, 2021b]

For BIMeaser:

- D6.6 Decision-support tool (confidential report) [BIM4EEB, 2021d]
- D6.9 Report on adoption of BIM-assisted Energy refurbishment assessment tool (confidential report) [BIM4EEB, 2021e]

For Fast Mapping Toolkit:

- D5.5 Technical report on testing and validation results (public report) [BIM4EEB, 2021c]

For BIMPlanner:

- D7.1 Server software to manage interlinked BIM-workflow data for construction production management (confidential report) [BIM4EEB, 2021f]

For BIM4Occupants:

- D6.8 Ambient User Interface (public report) [BIM4EEB, 2020d]
- D7.2 Web-based responsive user-interfaces (public report) [BIM4EEB, 2021g.]

For BIMcpd and AUTERAS:

- D6.3-5 BIMcpd Toolkit - Demonstration preparation and key performance indicators (confidential report)[BIM4EEB, 2020b]
- D6.2 Methods and tools for selecting devices and linking them to the generic model (public report) [BIM4EEB, 2020a]

In addition, another related document is the D8.1 Report on management of real Best Practice Examples (public report) [BIM4EEB, 2021h] regarding demo sites and sensors choice and set up, and the D3.5 Measurement and Verification protocol concerning KPIs definition [BIM4EEB, 2019b].

2 Description of the Italian pilot site

The building under examination is in Monza, one of the biggest cities in northern Italy, in Via della Birona 47. The building, completed in 1981, is a residential social housing managed by ALER Varese – Como – Monza Brianza – Busto Arsizio (ALER VCMB), and it is a structure with nine floors and sixty-five apartments in total, equipped with central heating. It is composed of plastered external facades and fair-faced concrete stairwells and fronts.
It has never undergone renovation activities or energy refurbishments and in fact, the conservation status of the building is relatively poor. There are signs of loss of plaster and flooring as well as damage to the concrete cortical surface.
The building is a good representative example of residential public housing in Italy because of its size and age.

Figure 1 - Italian demonstration site before, during and after the renovation

2.1 Renovation interventions

To improve the performance of the residential building, two activities were carried out. The realisation of insulating facade coat (ETICS) and the replacement of external windows with PVC windows were the main renovation interventions that took place. The interventions took place over the 4 facades of the building. The following images highlight the portions of the main facades EAST (Figure 2) and WEST (Figure 3) of the building. Each portion is highlighted to identify the façade portions that were monitored using BIMPlanner. Due to the difficult availability of scaffolding the works were divided, involving different parts of the building in sequence, so that the same portion of scaffolding could be reused for different works. Initially, the work was carried out on the two short sides of the building facing north and south, and then on the portions of the building facing east and west.

The work was carried out on portions E1 and E3at the same time, followed by work on portion E2. Then, the W1 portion was interested by the intervention and after its completion the works were completed on the W2 portion.

Figure 2 - E1, E2 and E3 portion of the East façade

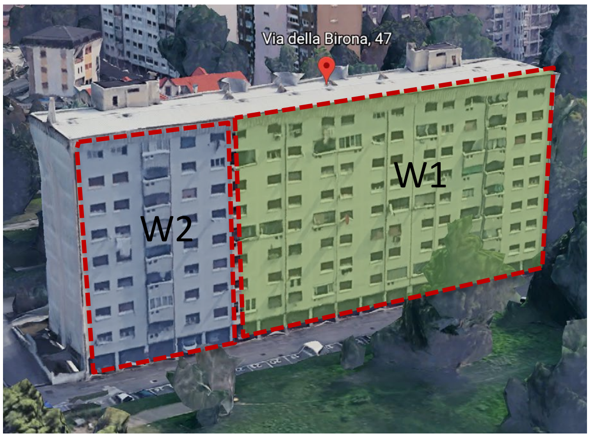


Figure 3 - W1 and W2 portion of the West façade

Figure 4 - Detail of ETICS installation

Figure 5 - Ongoing ETICS installation and windows systems replacement on East Facade

2.2 Development of the IFC model of the building

ALER has technical employees who supervise the design activity and follow the work of the contractors. Before the BIM4EEB project all the design activities were managed in 2D CAD, using Autocad at a basic level and not advanced use.

The BIM model of the building was created using ALLPLAN software, since the FastMapping tool and the IFC model creation functionality had not yet been released at the time when the project required a Via della Birona Building model to test the Energy Performance Analysis tool (BIMeaser), project data to include in the Common Data Environment (BIMMS) and data coming from the sensors to manage in the BIM4Occupants and BIMcpd applications.

The model creation process, and in general the new BIM approach, were also developed thanks to the training courses developed for this purpose by Lombardy Region through the regional society Polis Lombardia, with teachers from the Politecnico of Milan.
Regarding the model creation process, ALER archives stored some paper tables from which the model was set up. Inspections were carried out in advance to check the available data. The following process involved the implementation of the IFC model through the creation of both floor levels and interoperable attributes of the elements present (Figure 6).

Figure 6 - IFC model of Via della Birona Building

2.3 Sensors set up and placement

2.3.1 Sensors distribution in Italian pilot site

Sensors and meters have been installed in the Italian pilot site according to the following schema (re-elaborated from D8.1 that takes into consideration the changes described in the following chapters).

Table 1 Sensors distribution for the Italian pilot site

		Common space	A GF			B GF		C GF		D Floor 3			E Floor 3		F Floor 3			G Floor 6		H Floor 6			I Floor 7			L Floor 5			M Floor 7		N Floor 1			O Floor 6		
DEVICES		Single room space	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	bedroom
Multisensor	Temp	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-	x	x	x	x	-	x	x	-
Multisensor	Humidity	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-	x	x	x	x	-	x	x	-
Multisensor	Occupancy	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-	x	x	x	x	-	x	x	-
Multisensor	Luminance	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-	x	x	x	x	-	x	x	-
IAQ Sensor	CO_2	-	x	-	-	x	-	x	-	x	-	-	x	-	x	-	-	x	-	x	-	-	x	-	-	x	-	-	x	-	-	-	-	x	-	-
IAQ Sensor	PM2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IAQ Sensor	PM10	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IAQ Sensor	VOC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Radiator Heat Cost Allocator		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Thermostatic vale		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electric power meter		-	-			x		-		-			-		-			-		-			-			-			-		-			-		
GAS meter		-	-			-		-		-			-		-			-		-			-			-			-		-			-		
HUB		x	x			x		x		x			x		x			x		x			x			x			x		x			x		
Internet connection		x	x			x		x		x			x		x			x		x			x			x			x		x			x		

The 13 apartments are well distributed and representative of the overall performance of the building. Eight apartments are three-room apartments, while the remaining five are two-room apartments. Added to the list there is a common space placed at ground floor level.

Since the beginning of the monitoring phase, the inhabitants of two of the originally selected apartments decided not to continue their participation in the project. They were substituted by two other tenants, who followed the project till the conclusion. The original baseline consists of 9 apartments and a common space. **Additional 4 apartments were added near the end of the project following engagement activities that raised the curiosity of additional participants, as described in chapter 3.2.4.3**.

2.3.2 Changes in the predefined sensor setup

Due to an unexpected shortage in Indoor Air Quality sensors, the research team made a change in the sensor set-up with respect to what was initially stated in deliverable D8.1. A multisensor by Netatmo has been chosen as a substitute, despite the lack of measurements capabilities in VOC and PM2.5 particles. A brief description of the device and its main features is in the following section.

Figure 7 - CO_2 sensor [Netatmo, 2022]

Smart Indoor Air Quality Monitor by Netatmo is a device that tracks air quality giving the user personalized recommendations about safety and healthy. Netatmo's sensors are designed and tested to measure CO_2 with a range of 0-5000 ppm. Besides these key factors of air quality, Netatmo provides the measurement of temperature, humidity and sound too. The CO_2 level can be read both on the sensor display by a light indicator and in the app accessible by different devices, together with other values.

Table 2 Technical data Multipurpose sensor

Sensors	CO_2: 0-5000 ppm ± 50 ppm (from 0 to 1,000 ppm) or ± 5% (from 1,000 to 5,000 ppm) Temperature: 0°C to 50°C ± 0,3°C Humidity: 0-100% ± 3% RH Ambient noise: 35 dB to 120 dB
System requirements	Wi-fi connection Smartphone or table with IOS 9 or later, or Android 4.2 or later
Connectivity specifications	Working wi-fi connection: Wi-Fi 802.11 b/g/n compatible (2.4GHz) Supported security: Open/WEP/WPA/WPA2-personal (TKIP and AES)
Power	Powered by USB wall adapter
Dimensions	45x45x155 mm (LxWxH)

Due to the age of the **gas meters** installed in the individual flats it was not possible to provide a system for measuring gas consumption, but, since these meters are dedicated only to gas used for cooking, they were considered not relevant for the monitoring process of the building renovation. Centralized Heating is used at the building level, while these individual meters are specific to individual flats. It was possible to measure gas consumption for the entire building through a dedicated gas meter and it would be possible to allocate the consumption to the single apartments (and to the single radiators) through the existing thermostatic valves and sensors, installed in accordance with the regional law. .

SIM operated Wi-Fi routers were installed in each flat. Two different types of **routers** were used for the installation due to the logistical requirements of equipment integration and availability.

The modem Alcatel Wi-Fi 4G LTE enables the Wi-Fi connection up to 10 devices. Technical data in Table 3.

The second router is a TP link mobile hotspot Wi-Fi supporting 4G FDD/TDD-LTE standard.
Technical data in Table 4.

Figure 8 - Modem Wi-Fi 4G LTE [Alcatel, 2022]

Figure 9 - Mobile Wi-Fi 4G LTE [tp-link, 2022]

Table 3 Technical data Modem Wi-Fi 4G LTE

Frequency	4G: 800/1800/2600 MHz
	3G: UMTS: 900/2100 MHz
	EDGE/GPRS: 850/900/1800/1900 Mhz
Connectivity	300 Mbps download
	50 Mbps uplink

Table 4 Technical data Mobile Wi-Fi 4G LTE

Frequency	4G: FDD-LTE B1/B3/B5/B7/B8/B20 (2100/1800/850/2600/900/800 MHz)
	TDD-LTE B38/B40/B41 (2600/2300/2500 MHz)
	3G: HSPA+/HSPA/UMTS: B1/B5/B8(2100/850/900 MHz
Connectivity	150 Mbps in download
	50 Mbps in uplink

2.3.3 Sensors' positioning and installation

Given the 13 apartments selected for the project purpose, different kinds of sensors have been installed to monitor thermal and visual comfort, indoor air quality, acoustics, lighting levels and electric power consumption. To integrate data deriving from these different sensors one hub for each apartment has been installed.
The inhabitants are mostly single, elderly people, and for this reason plug and play solutions with minimal (or better, zero) user required intervention for the sensors have been chosen. Elderly people will were supported by ALER and Polimi for any need or question related to sensors, for help with questionnaires and for the use of BIM4EEB tools. Most of the installed sensors were battery-powered so as not to burden users' bills, but also to allow greater installation flexibility, although this choice required several maintenance interventions for battery replacement.

At the beginning of the project most of the inhabitants were not equipped with a home internet connection and, in any case, it was decided to have a dedicated internet connection for the monitoring system is in charge of ALER to avoid using internet infrastructure owned by the tenants and issues with tenants' different connections (cable, mobile phone, different operators) and with different behaviours (for example, the habit of turning off Wi-Fi at night).

Multisensor A (temperature, HR, CO_2, sound pressure) and B (temperature, HR, illuminance, presence) were installed in the living room, together with the hub and the Wi-Fi router for the internet connection. Multisensor B was located in the bedrooms.

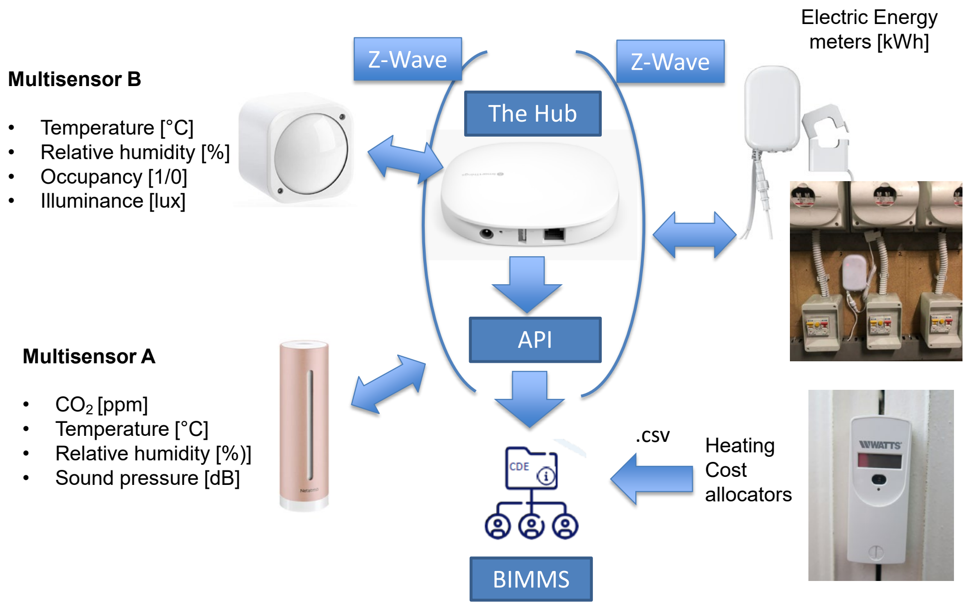


Figure 10 - Sensor data flow and installation representation – General overview

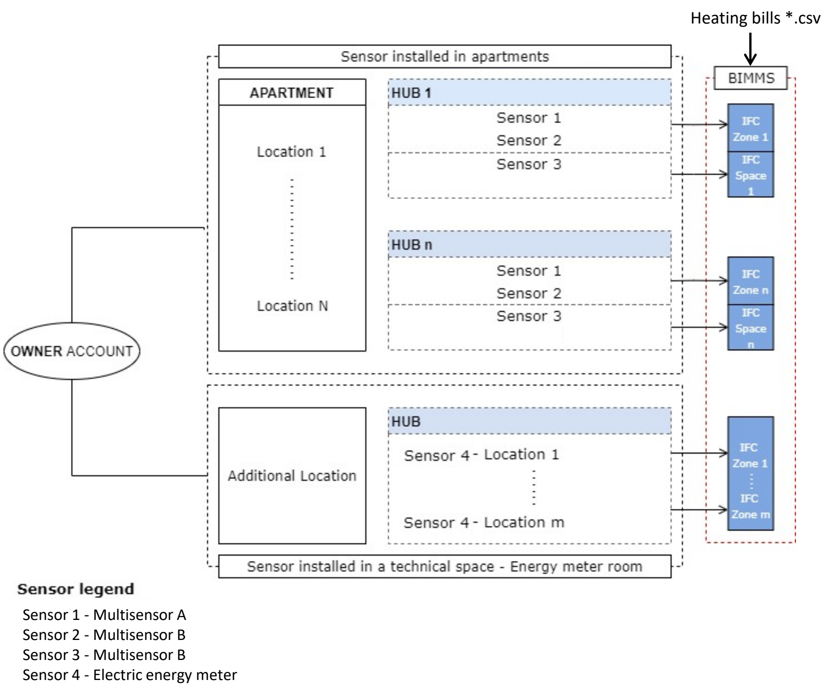


Figure 11 - Sensor data flow and installation representation – Detailed schema

The wireless electric energy meters were installed in a technical space in the basement where all the apartment standard meters are located. A dedicated hub collected the data coming from all the installed sensors.

The installation schema is presented in Figure 10. Each sensor is connected to a central connection unit

(HUB). BIMMS developed in WP4, retrieves all the data coming from the sensors through dedicated API. For this purpose, IFC zones, for the sensors located in the living room, and IFC spaces, for the sensors located in the bedroom, have been associated within the BIM Management System following the schema in Figure 11.

The use of sensors capable of registering multiple environmental variables simultaneously required a careful evaluation of their positioning. The positioning of the sensors was deigned to avoid problems related with:

- furniture presence that can interfere with the sensor’s recordings,
- glare in case of facing direct sunlight,
- proximity to heating and cooling systems,
- proximity to openings and ventilation systems,
- installation on external non-insulated walls.

Therefore, in the case of battery-powered wall-mounted sensors it was necessary to ensure that the following variables of Temperature, Relative humidity, Illuminance level and Motion recording were representative of the environment considered.

The chosen positions were a compromise to ensure that the recording of each measurement was a good estimate and that the recording and the significance of one environmental variable was not more disadvantaged than any other. Hence, it was sought to have an installation that was standardised, optimised and repeatable between the various flats. In addition, the choice of the position was made to permit the comparison of the data between different apartments, creating the minimum disturbance to the inhabitants.

To allow better temperature and humidity recordings the sensors were located near an internal wall and as far as possible in the centre of the room, to detect average environmental conditions (Figure 13).

Considering illuminance and motion, the positioning of the sensors was also identified to record adequately the movement of users. For this reason, the height of the sensor and the choice of the position on the wall required even more care, especially concerning the existing furniture. In the selected installation scenario, the view cone of the sensor had the maximum effective opening, allowing optimal detection. The sensor itself was oriented towards the areas most likely to be used by users. On the other hand, since it was not possible to measure the illuminance level on the ceiling or on the horizontal working plane, the wall positioning of the multi-sensors should have been a concession for repeatable illuminance level recordings among the different apartments and that could therefore allow the results to be compared. The position at 1/2 or 2/3 of the depth of the room, concerning the window, is also representative of an illuminance condition in favour of safety, as this distance is normally at the limit of the visual comfort zone in natural lighting conditions (Figure 12, Figure 13 and Figure 14). Illuminance measurements with additional sensors were conducted during the installation, to check the installation hypothesis.

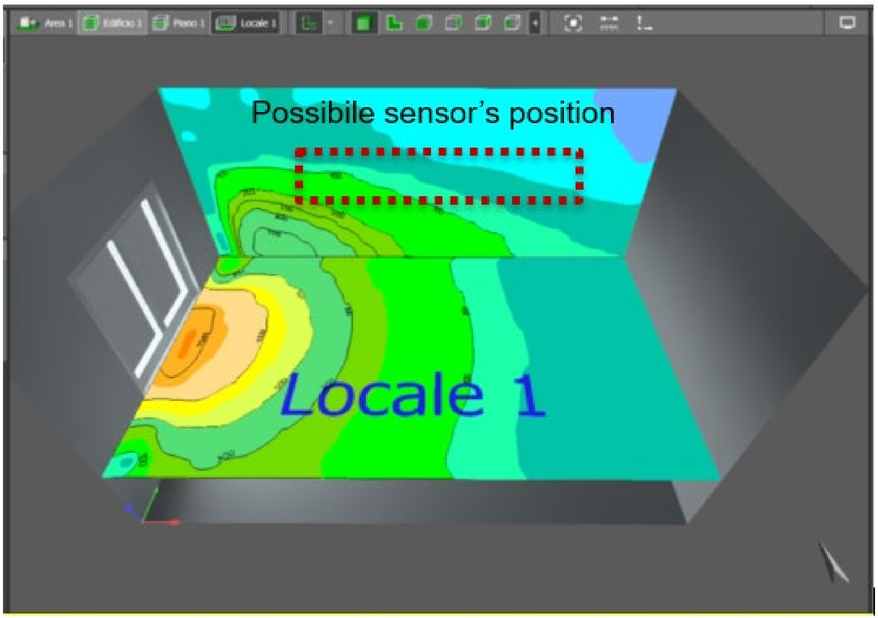


Figure 12 – Example of Illuminance distribution on horizontal and vertical surfaces in a standard room (Location Monza Latitude, 21/06 h12)

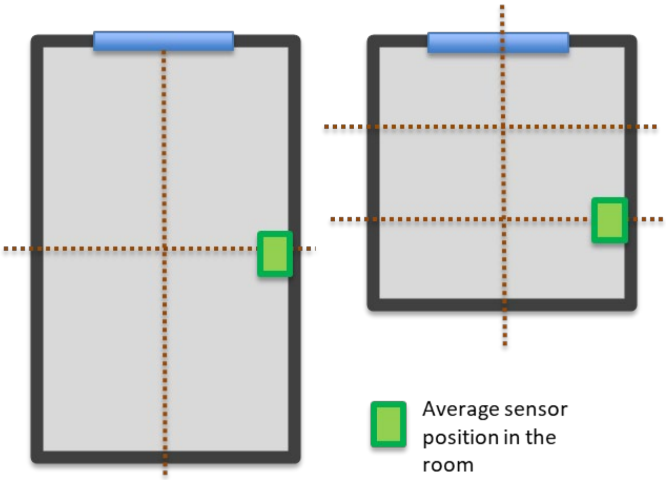


Figure 13 - Multisensor B - Living Room and Bedroom - On the wall perpendicular to the window at ½ or 2/3 of the room depth, height of 2.15 m

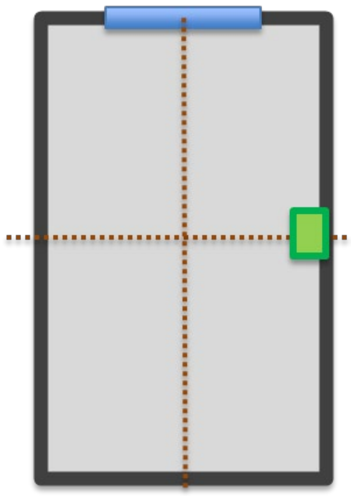


Figure 14 - Multisensor A - Living Room - On a desk/shelf/table (And possibly in the middle of the room)

A floor plan for the selected apartment and an example of the installation is provided in Annex I.

3 Evaluation of the pilot

3.1 KPIs to be demonstrated

The Report on the management of real Best Practice Examples (D8.1) describes the list of the Key Performance Indicators that are used in evaluating the Italian demo site.
The full list is reported in Annex II – List of the KPIs with KPIs divided in two categories: the primary ones, highlighted in red, refers to the main project goals as stated in the Grant Agreement. The secondary ones include additional analysis that the project team considered relevant during the development of the project. Italian demo site was proposed as a demonstrator of all the developed tools. After the assignment of the KPis in the D8.1 there were some changes, mainly related to secondary ones.

Time and cost indicators REP 5, 6, and 7, such as environmental ENV 5 were not assessed because these indicators are not relevant for the tools developed, as well as no baseline for the comparison exists or can be retrieved. These data are not usually collected and stored. Future development should promote and include this retrieval.
Although BIMcpd can analyse these data, environmental indicators ENV 2, 3 about PM2.5 and VOC content were not quantifieddue to a lack of capability of the air quality sensors installed. In any case air quality assessment is done through the measurement of CO_2 content. This issue and the related motivation were described in the previous chapter about sensors and set-up change (chapter 2.3.2).

3.2 Tool demonstration process

In order to test the different tools, a generic procedure followed by KPIs demonstration is conceived and represented in Figure 15 and was followed by the most of the tools.
The generic process involves a request for input data from the building owner to the tool developer. These data allow a preliminary demonstration of the tool operations after the testing phase described in D4.10. This preliminary phase is followed by one or more demonstration workshops where the main functions are presented and demonstrated. This is an opportunity to resolve any preliminary doubts.
Afterwards, the building owners, but in general, the users of the tools, which in the case of BIM4Occupants are the tenants, use the tool continuously.
In parallel, the tool developers continue to monitor the data flow and remain available to users to clarify doubts and propose solutions to any problems.
At the end of the period defined for the demonstration, the tool developers analyse the data obtained and participate in the verification of the KPIs and their approval with respect to what is declared in the DoA and Deliverables D3.5 and D8.1.

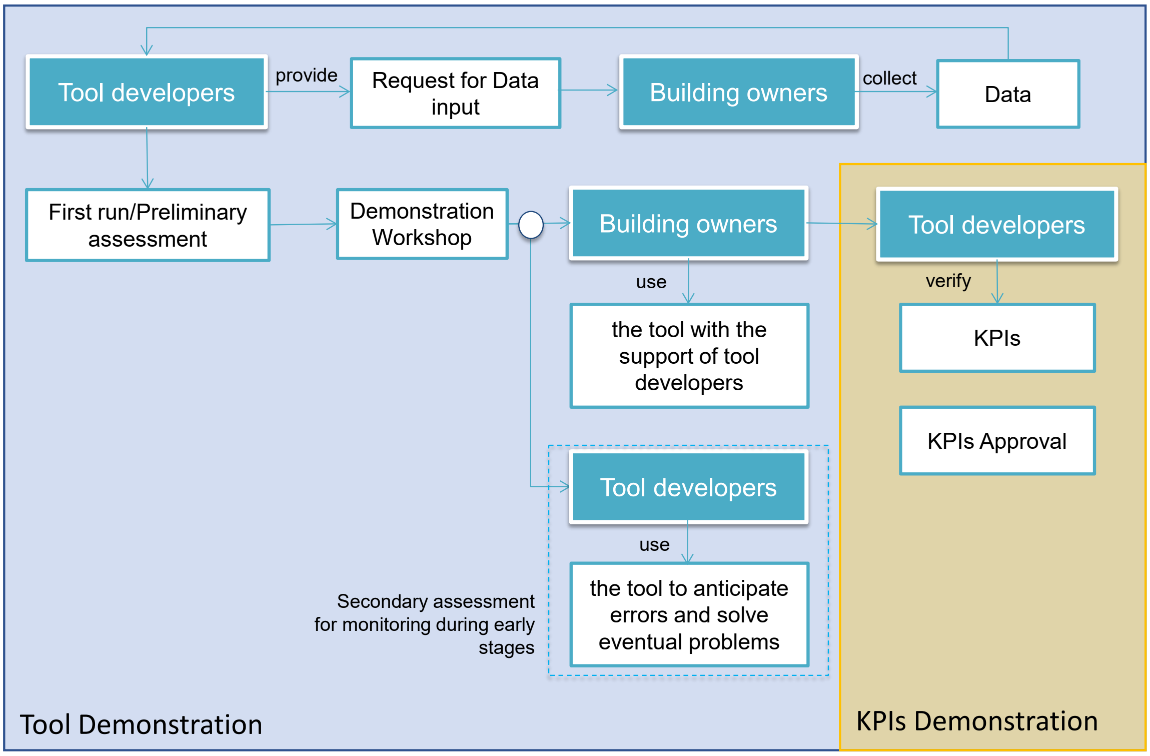


Figure 15 - Demonstration procedure workflow

3.2.1 BIMMS Demonstration process

The BIMMS has been used in Italy demonstration site as the main common data environment where has been stored different kinds of data like the building's BIM model, sensors streaming, activities and alerts. The BIMMS provided the resource management functionalities to upload, share, and edit files between the users of the demonstration site. The demonstration applied all the test cases defined previously in testing and validation activities (D4.10) that involved owners, inhabitants, and professional users as designers, technical providers, and developers.

The test cases include the main BIMMS' resource functionalities to perform the files upload, make revisions, set permissions and share the resources. The inhabitants used the BIMMS to receive a flow of information about their homes and building through the integration of the BIM4EEB tools connected to the BIMMS to retrieve and send alerts, notifications, feedback and sensor measurement streaming. This test includes other tools (BIM4Occupants and BIMPlanner) used to create alerts and notifications through their interfaces and to show (BIM4Occupants) the sensor streaming data records in the BIMMS using its IoT functionalities.

The demonstration also involved the owners and professional users that simulate their activities through cycles of upload and sharing of resources (documents, BIM models, drawings, etc.), implementing for each one a feedback loop based on approval workflows and resource update through revisions and versioning. The 3D BIM Viewer was also used in the interaction loop to collect feedback from the owner and the professional. Finally, the integration of external tools like the BIM authoring tools that were able to connect to the BIMMS was demonstrated.

The BIMMS were officially presented in a workshop held in November 2021 to a broader audience of professional users, to show how to use the BIMMS in a typical professional context focusing on specific functionalities to manage document resources and BIM models. The BIMMS has been presented with a set of tutorials that explained the main functionalities and described with small hands-on sessions. The participants had access to a sample dataset to try the BIMMS' features. The attendees came from

Politecnico di Milano, Regione Lombardia, and ALER with a wide range of roles as architects, engineers, technical advisors and consultants. Another workshop was held in Politecnico di Milano in November to introduce the BIMMS' functionalities to academics, researchers and to a class of international undergraduate university students.
A further presentation was done on January 19th as the final workshop for the Italian demonstration.

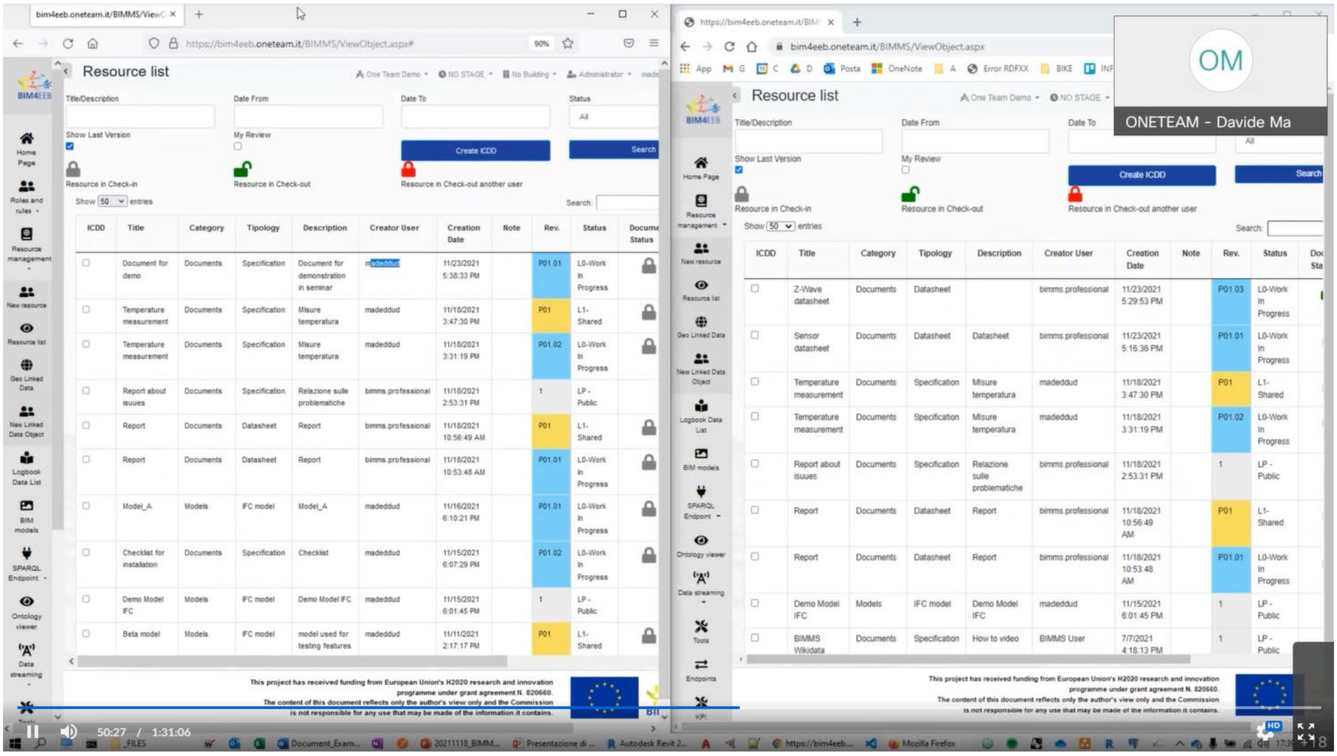


Figure 16 - Image from the workshop

BIMMS accounts were also created by the inhabitants, to access the functionalities of BIM4Occupants. The details are then reported in chapter 3.2.4.

3.2.2 Fast mapping demonstration process

The activities of scanning and test mapping took place in via della Birona 47 building on November 2nd and 4th 2021 in the morning and afternoon.

During November 2nd there was a small workshop activity with ALER, Regione Lombardia and Polimi.

November 2nd – morning (Apartment 18 – third floor)

During the first day of the tool demonstration, an empty apartment was the object of study. It is a 67 m^2 apartment characterised by two bedrooms, two bathrooms, a kitchen and living room. The survey activity was characterised by several steps. Firstly, the apartment was surveyed by using the laser scanner *Imager 5010*. This instrument needed a proper setup before its use such as the definition of Mpt and quality. Since the apartment was quite simple to analyse a medium coverage setup was chosen. 18 scans were done and as a result points cloud of the surveyed rooms were reproduced within the software released by the laser scanner producer and merged in order to recreate the whole apartment.

Figure 17 - Equipment and different phases of the survey

November 2nd - afternoon

In the afternoon of November 2nd the second part of the demonstration was carried out. This consists in importing and downloading the point cloud in the companion app on a PC.

Specifically, the point cloud was imported in 3D Unity. The exercise was based mainly on the use of the HoloLens device, where the point cloud can be viewed and a simplified IFC object was created and representative of a window surface. This step was performed for the sake of simplicity in a single room and it took place with the participation of ALER, Polimi and Regione Lombardia, who had the chance to use the HoloLens headset (Figure 18).

Finally, a sensor stick was used to identify plants hidden within the walls such as electric wires and plumbing.

Figure 18 - Involvement of ALER and Regione Lombardia in the Italian workshop on November 2nd 2021

During the demonstration activity, some communication problems have arose between the sensor stick and the HoloLens device. Consequently, it was not possible to see in real-time within the HoloLens device the mapping made by sensor stick, but the mapping test activities were crucial to give an estimated time for surveying the interior spaces of the building. For this reason, the time reported in Table 6 and Table 8 should be considered indicative and mainly related to the activity of moving the sensor over the building surfaces checking through the laptop screen any change in the values recorded by the sensors.

November 4th – morning (Apartment I – sixth floor)

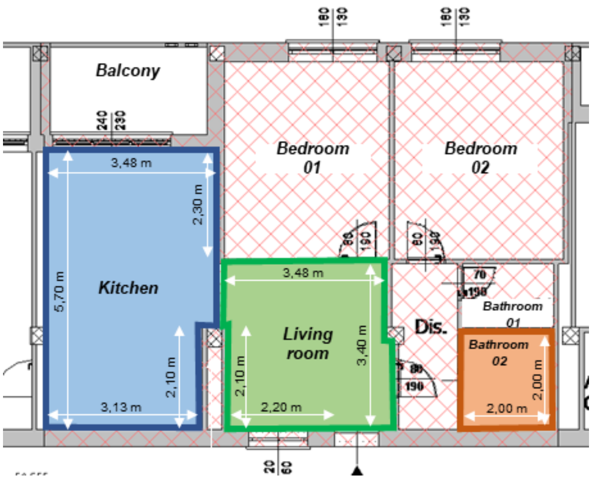


Figure 19 - Apartment H plan

The demonstration activity of the Fast Mapping tool continued on November 4th with the survey of an occupied apartment located in via della Birona, 47. The apartment has a surface of 68 m^2 and it is characterised by two bedrooms, two bathrooms and a space for a sitting room and kitchen. The same activities performed in the empty apartment were carried out in the selected apartment. Hence, firstly the whole apartment was surveyed by the laser scanner and secondly, it was mapped with the HoloLens device and the sensor stick.

In Table 6 and Table 8 below the time necessary to survey the flat is reported. Surveyed rooms are kitchen/sitting room and bathroom.

In particular, about 6 minutes for the setup and about 6 minutes for a preliminary analysis are necessary. Moving the equipment and the preliminary analysis take approximately 2 minutes each. Accordingly, laser scanning allows a 90% reduction in time for surveying, compared to a standard process-

Table 5 Area and perimeter of the rooms surveyed in the Apartment I

Room name	Area of each room (m^2)	Perimeter of each room (m)
Bathroom 02	3.7	7.7
Kitchen+ sitting room	30.6	29.6

Table 6 Survey time and total area surveyed of Apartment I

Room name	Survey Time (min)	Total area surveyed (m^2)
Bathroom 02	3.3	32.4
Kitchen + Sitting Room	20.6	87.4

November 4th – afternoon (Apartment 18 – third floor)

In the afternoon of November 4th the activity moved again to the inhabited apartment of the first day considering the same rooms as in the case of the occupied apartment for a comparison purpose.

Unlike the occupied apartment, the flooring was not surveyed because of dust and dirt that could ruin the sensor stick and make the procedure impracticable.

Figure 20 - Apartment n°18 plan

Table 7 Area and perimeter of Apartment n° 18

Room name	Area of each room (m^2)	Perimeter of each room (m)
Bathroom 01	3.4	7.4
Kitchen + Living room	28.1	26

Table 8 Survey time and total area surveyed Apartment n° 18

Room name	Survey Time (min)	Total area surveyed (m^2)
Bathroom 01	3.4	22.4
Kitchen + Living room	20.7	82.8

From the demonstration activity, several considerations regarding the use of the sensor stick instrument and its functions can be made and are reported in the Confidential Deliverable of the project D5.5.

Difficulties emerged in the alignment of the point cloud, consequently to the laser scanner survey, due to the presence of a lot of people inside the room. Then the process was repeated several times to get to a good alignment. An empty space is necessary to speed up the process.

The activity tested also the ability of the sensor stick to find wires and plumping. Specifically, comparing the survey in the two apartments, the electric wires are easier to find by the voltage sensor in the inhabited apartment where the electricity is present, while they can be found by the capacitance sensor in the empty apartment where the electricity is not present. In addition, Italian buildings are characterised by a structure with metal bars that make the use of sensors impracticable to detect wires in the floor or ceiling. Also the presence of Wi-Fi and smartphones can interfere with the use of sensor stick, so it is better to switch them off for a proper survey. Dust is also an issue in an inhabited apartment and can interfere with the full functionality of the sensor over the survey period.

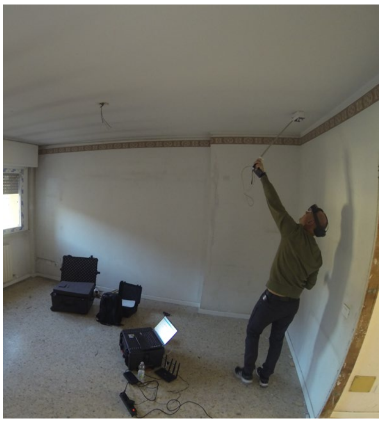
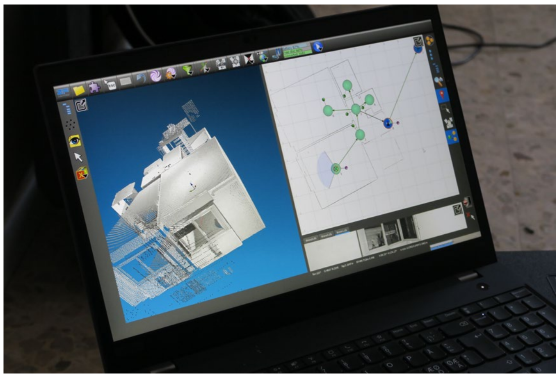




Figure 21 - Survey with sensor stick

April 19th – Morning and Afternoon (Apartment I – sixth floor and Apartment 18 – third floor)Additional tests were conducted in the two previously investigated flats to re-evaluate both the effective connection of the devices and the mapping possibilities of the implants. It was possible to appreciate the realtime operation of the stick, although due to a connection difficulty it was not possible to record and visualize data via Hololens. Flat 18, empty during the previous test campaign was finally occupied and the analysis was therefore repeated to test the mapping of the installations in the flat. The day was attended by both ALER and POLIMI. Both were able to test the devices, as were the tenants of the flats.

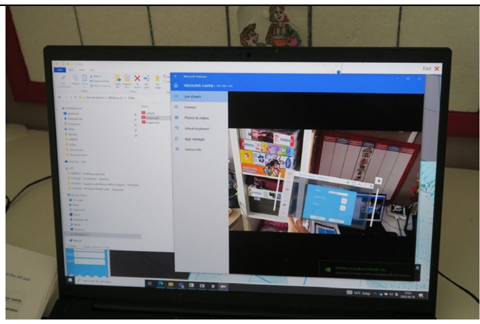




Figure 22 - Second Survey with sensor stick

3.2.3 BIMeaser Demonstration process

BIMeaser is a BIM Early Stage Energy Scenario tool with the main purpose (use cases) of:

- enabling easy build-up of the ”As-is” energy and indoor climate model in the early design stage (Concept design & Preliminary design),
- applying the renovation scenarios to the “As-is” model,
- presenting the impact of each renovation scenario in terms of Owners Project Requirements (OPR).

The expected benefit is that BIMeaser can speed up the decision making, enhance the collaboration between design domains, enable cross-domain transparency in technical details and finally result in better indoor climate and energy design.

Using real-world pilot buildings of BIM4EEB in Italy and Finland, the BIMeaser refurbishment scenario simulation functionalities were first tested in qualitative design workshops with construction professionals. The workshops took place in the two countries. Part two of the demonstration evaluated how much time could be saved by using the BIM-assisted BIMeaser scenario simulator compared to manual data entry. Participants at the Via Birona building workshop (Dec 2020) came mainly from; ALER Varese-Como-Monza Brianza-Busto Arsizio, other ALERs (Lombardy Regional Companies for Residential Construction) and the Region of Lombardy (for a total of 17 technical experts) as well as researchers from VTT and Polimi (4 participants).

According to the use cases above, the building was modelled and the following real-world renovation measures were applied to it in the workshop:

- insulation of the outside walls, 120 mm and plastering on top of the existing wall,
- replacing the roller shutters,
- replacing the windows.

In addition to the real-world measures, also a photovoltaic system and a new condensing boiler were applied although there were no plans to apply them in the real building.

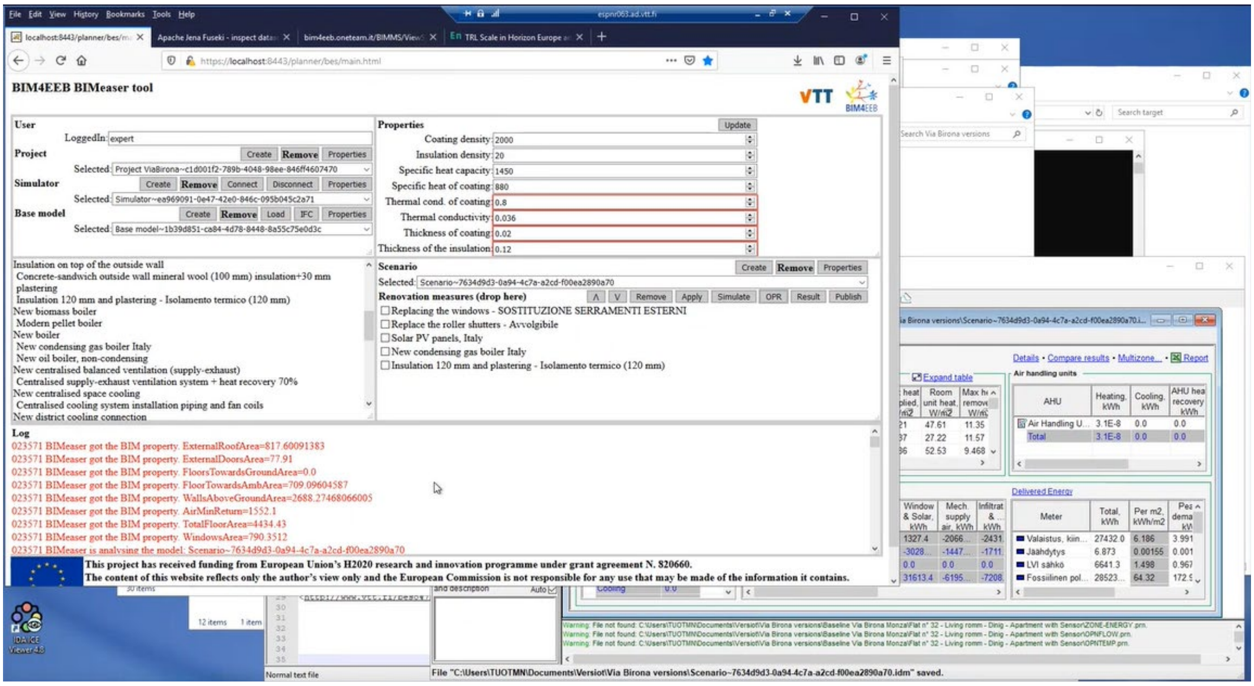


Figure 23 - The Via Birona (Italy) renovation scenario defined in the BIMeaser-tool.

Finally, the results presented in Table 9 were discussed in the workshop.

Table 9 The Owners Project Requirements (OPR's) in the Via Birona (Italy) workshop.

	Cost			Energy					Comfort	
Scenario	Operational energy cost [€/floor-m²y]	Payback time [years]	Investment [€/floor-m²]	Primary energy [kWhpr/m²y]	RES share [%]	Heating [kWh/m²y]	Cooling kWh/m²y]	Electricity [kWh/m²y]	Summer thermal h/year,zone (T_{indoor} >27 °C)	Summer thermal °Ch (T_{indoor} >27 °C)
Baseline	14.87		0	198	0.01	123	0	35	1763	4878
Insulation	13.39	31.4	46.41	171	0.01	97	0	35	2045	6108
PV panels	12.89	5.7	11.25	198	5.35	123	0	26	1763	4863
New condensing boiler	13.89	16.2	16	180	0.01	106	0	35	1763	4878
New windows + roller shutters[1]	13.6	56.8	72.18	174	0.01	101	0	35	1875	5429
All	9.55	27.4	145.84	136	8.89	64	0	26	2284	7263

[1] The effect of roller shutters was negligible.

The demonstration workshops and evaluation of the achieved time savings are described in detail in the confidential project report on the adoption of the BIM-assisted Energy refurbishment assessment tool (D6.9). The results of the evaluation are included also in this report. The overall increase in modelling time reduction can be concluded to be more than 75% with BIM assisted process compared to the manual modelling

3.2.4 BIM4Occupants demonstration process

The BIM4Occupants demonstration activities involved different subjects (Polimi, ALER, Regione Lombardia and Suite5) and were articulated in different initiatives all with the aim of increasing the awareness, trust of the inhabitants and their participation in the use of the tool. The initiatives are here described.

3.2.4.1 Preliminary activities

A preliminary workshop about the use of BIM4Occupants was held on June 11th 2021, before the final release of the tool. The purpose of the meeting was to arise the awareness of the inhabitants such as their curiosity about the tool and answering eventual questions. The meeting took place in the hallway of the building on the ground floor. The participants from Polimi, ALER and Regione Lombardia, were introduced to the inhabitants and the meeting began by thanking the inhabitants for their availability during the previous months, and allowing for the installation of the sensors. The audience was encouraged to ask questions. Then the tool BIM4Occupants was introduced. For the occasion, a wall was set up on which placed prints of the main screens of the tool. The same was commented directly with the users, showing the benefits of using the tool, as well as the main functionalities. Before the presentation, each inhabitant received a copy of the user manual that was provided to give further insights into the procedure.
Seven inhabitants, among those who agreed to participate in the monitoring activities, were present during the meeting. This meeting was an opportunity to understand the degree of digital literacy of the participants. It was found on this occasion, through direct dialogue with the participants, that:

- most of them are not in possession of a home internet connection,
- few inhabitants do not directly in possess a smartphone and/or an email address.

This information was useful for the development and planning of subsequent phases.

Figure 24 - Preliminary meeting with the Inhabitants for BIM4Occupants presentation

3.2.4.2 *Preliminary demonstration with selected inhabitants*

Among all the participants 3 inhabitants were involved in a preliminary demonstration of the tool. During a 1 to 1 demonstration session, the inhabitants were required to create BIMMS and BIM4Occupants accounts. These were some of the inhabitants that demonstrated a good level of digital competencies. The inhabitants had the possibility to use the tool and provide some preliminary feedback. They also demonstrated the effectiveness of the "negotiation" function, used to involve the users in planning the activities at the site. This functionality was then positively evaluated both by the inhabitants and the owner. Each inhabitant was informed through BIM4Occupants about the activities planned in his apartment. Then the inhabitant could have decided to accept the proposed scheduling or to propose alternative dates. As the contractor created new scheduling data for the apartments through BIMPlanner, the BIMMS tool retrieved this data and transfers it to the BIM4Occupant tool to be shared with individual apartment occupants based on common identifiers.

Through the tools, inhabitants refined the contractor's initial timing which initially proposed the installation of the new window systems on the days between 9 and 13 of August. The following negotiation process both in person and through the tool determined the definitive planning reported in Table 10 and the following figures.

Table 10 Approved and modified planning through BIMMS-BIMPlanner and BIM4Occupants.

Apartment	Requested Date for the intervention	Approved modified Planning
Apartment A	10 August	9 August
Apartment H	5-6 August	5 August
Apartment G	12-13 August	7 August

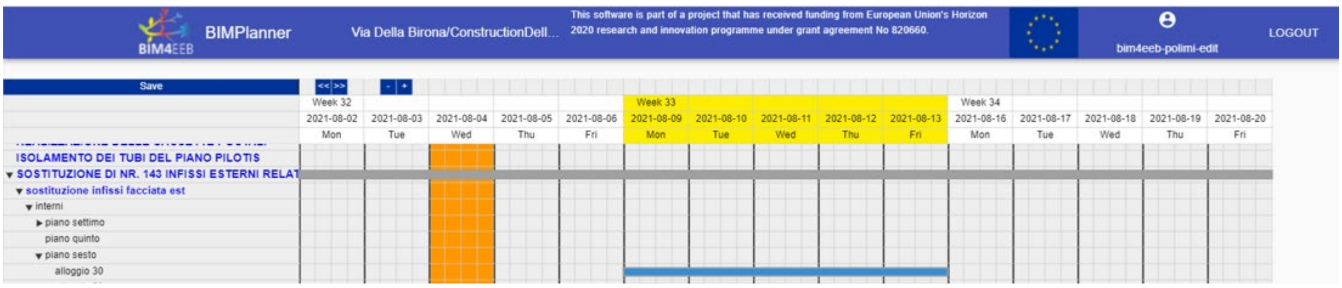


Figure 25 - Initial planning proposed by the contractor for "window exchange" (In Italian: SOSTITUZIONE DI INFISSI ESTERNI) for Apartment H – BIMPlanner interface

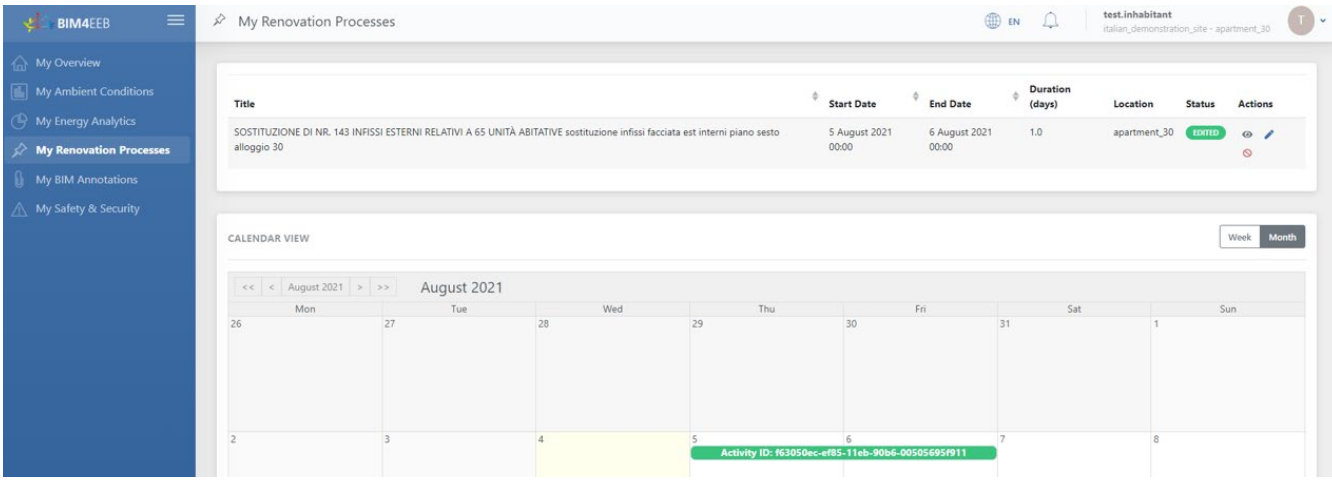


Figure 26 - Schedule change proposed by the inhabitants - BIM4Occupants interface

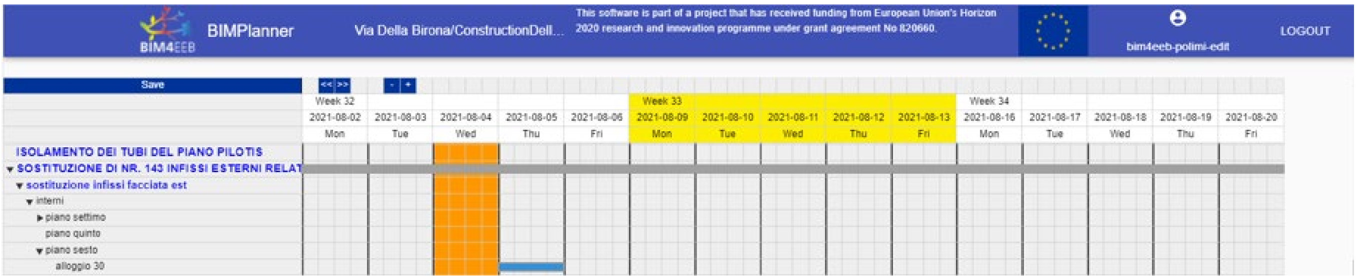


Figure 27 - Approved modified planning – BIMPlanner interface

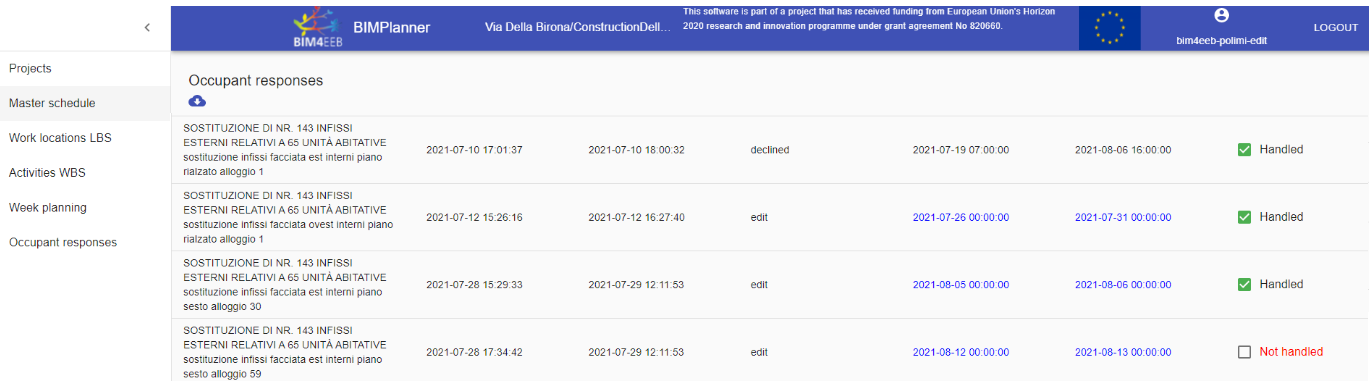


Figure 28 - Example of occupant's proposal of new timing for the activity in specific apartments. After contractor receive occupants' response the rescheduling will be done and new timing shared to occupant – BIMPlanner interface

3.2.4.3 BIM4Occupants Workshop

The extensive demonstration workshop for the BIM4Occupants took place officially on November 11th with the participation of 16 inhabitants of the Italian demo site, ALER, Regione Lombardia and Polimi, but before and after the main event, one to one meetings with selected inhabitants unable to attend the workshop occurred.

The workflow was characterised by different moments. After the greetings from ALER, Regione Lombardia and Polimi an overview of the BIM4EEB project and its toolkit, BIM4Occupants and its functionalities were presented to non-registered users. In conclusion, the daily activity focused on the BIM4Occupants tool and led inhabitants to use the platform in all its aspects.

The workshop with inhabitants aimed mostly at finalising the registration activities and to complete some data input in the app, supporting weak digital users in finalising their registration, such as in collecting feedback through a survey for social KPIs purposes.

Moreover, during one-to-one session with the inhabitants, BIM4Occupants paper manuals were provided and a search for new participants was conducted. **At the end of the morning suggestions and rules of good practice to reduce energy use and improve thermal comfort were introduced and discussed with those present.**
As a result of the workshop, new inhabitants expressed the will to participate in the activities. Increasing the number of inhabitants involved in the project from 9 to 13.

Figure 29 - Presentation of the project toolkit and recommendations to reduce the energy consumption

Figure 30 - General greetings to the Inhabitants with the involvement of Regione Lombardia and ALER

Figure 31 - 1 to 1 meeting with inhabitants

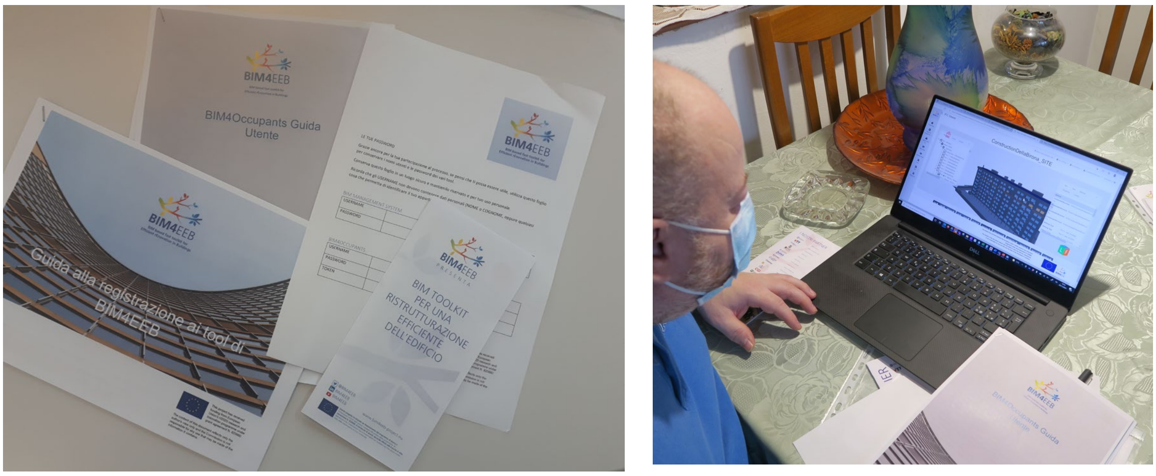
3.2.4.4 1 to 1 meetings

During the project, there were several occasions when both Polimi and ALER had the opportunity to organise 1 to 1 meetings with tenants to clarify doubts about the project, but also to provide general maintenance of the sensors (battery replacement or network issues).

On 24th November, meetings were organised with residents who, for various reasons, could not attend the workshop described above.

These were mainly tenants who required more structured IT support. They were given accounts provided by ALER for registration to BIMMS and BIM4Occupants, as well as copies of the user manual for both the tools. The first registration in the tool and the explanation of the single functions took place with Polimi and ALER.

In addition, ALER periodically maintained telephone contact with all the inhabitants, to encourage them in using the tools, collect feedback, and respond to the inquiry made by the tenants through the dedicated function within the BIM4Occupants Owner interface.



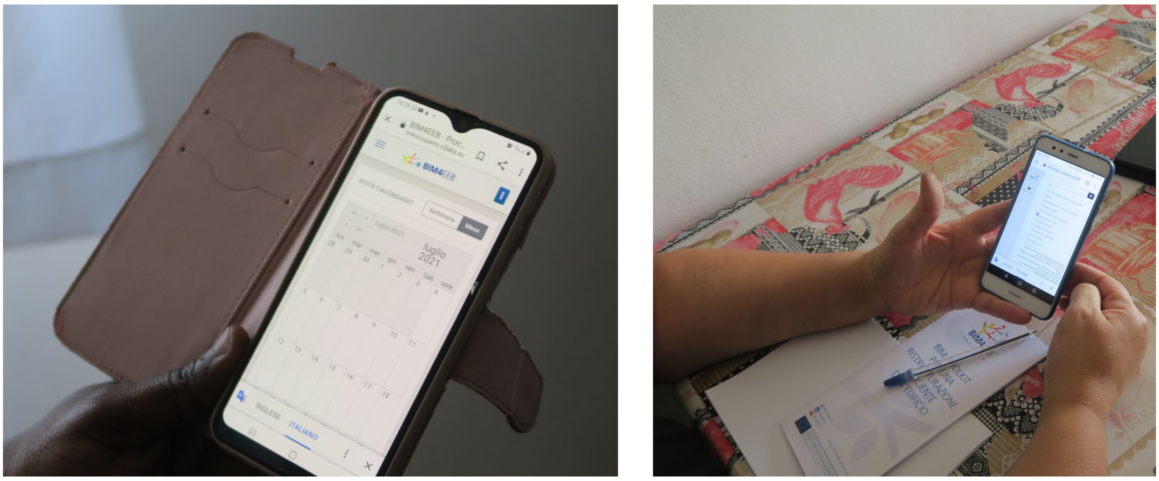


Figure 32 - (Top left) - Starter kit provided to the inhabitants, including BIM4EEB brochure, tools manual. (Other Images) – Inhabitants using the tool during 1 to 1 meetings.

3.2.5 BIMcpd/Auteras Demonstration

The BIMcpd workshop took place on November 24th where the functionality of the tool was demonstrated by four of the developers involved. The distinct tools for Data Management, Performance Evaluation and Constraint Checking were displayed and demonstrated using data received from the Italian demo site using the BIMMS API.

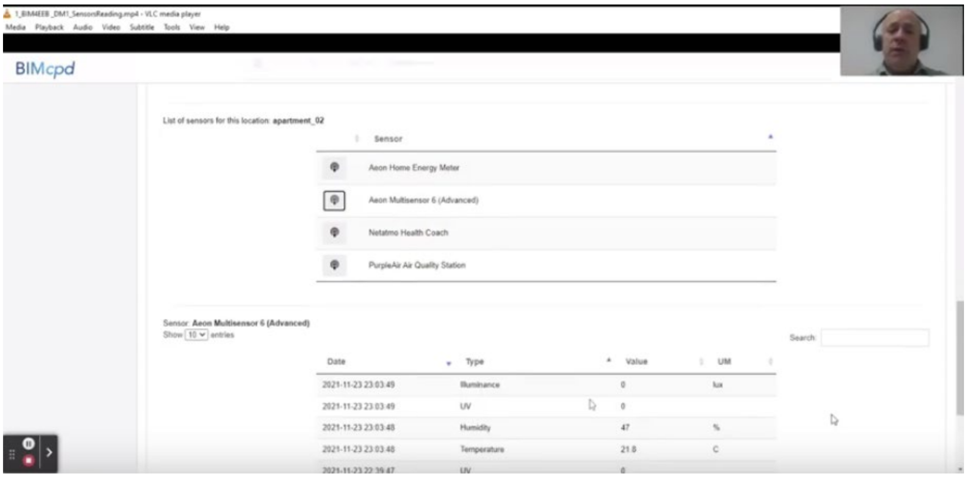


Figure 33 - Demonstrating the importing of data from a selected apartment (Multisensor) from the Italian demo site

The video of the main demonstration part of the workshop is available here: https://www.youtube.com/watch?v=IrCu_74M_GM
This was then followed by a question and answer session.

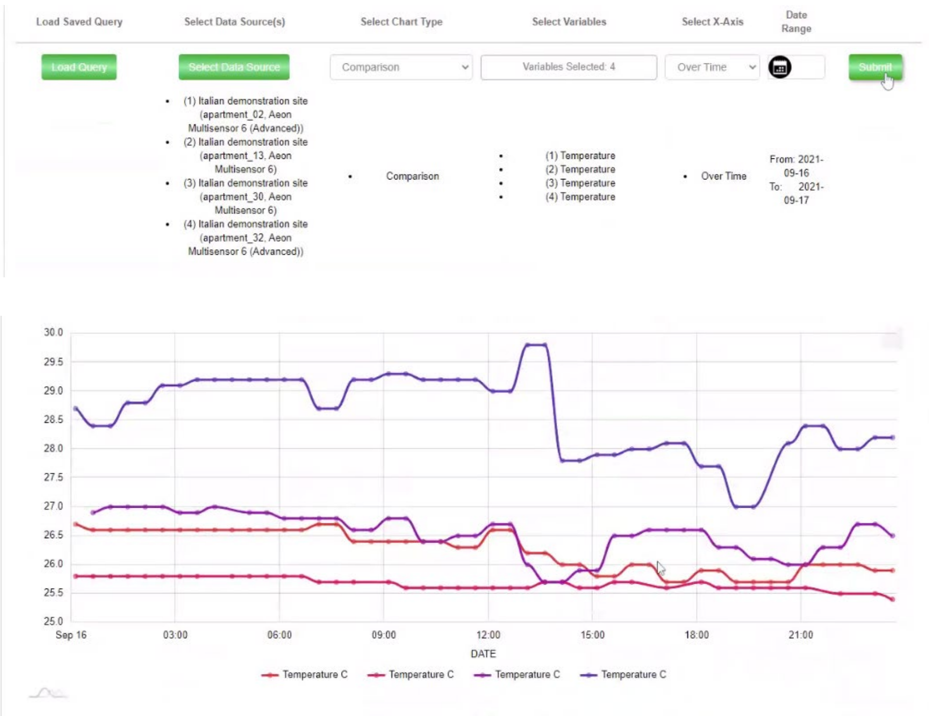


Figure 34 - BIMcpd comparing the temperature across 4 apartments in the Italian demo site

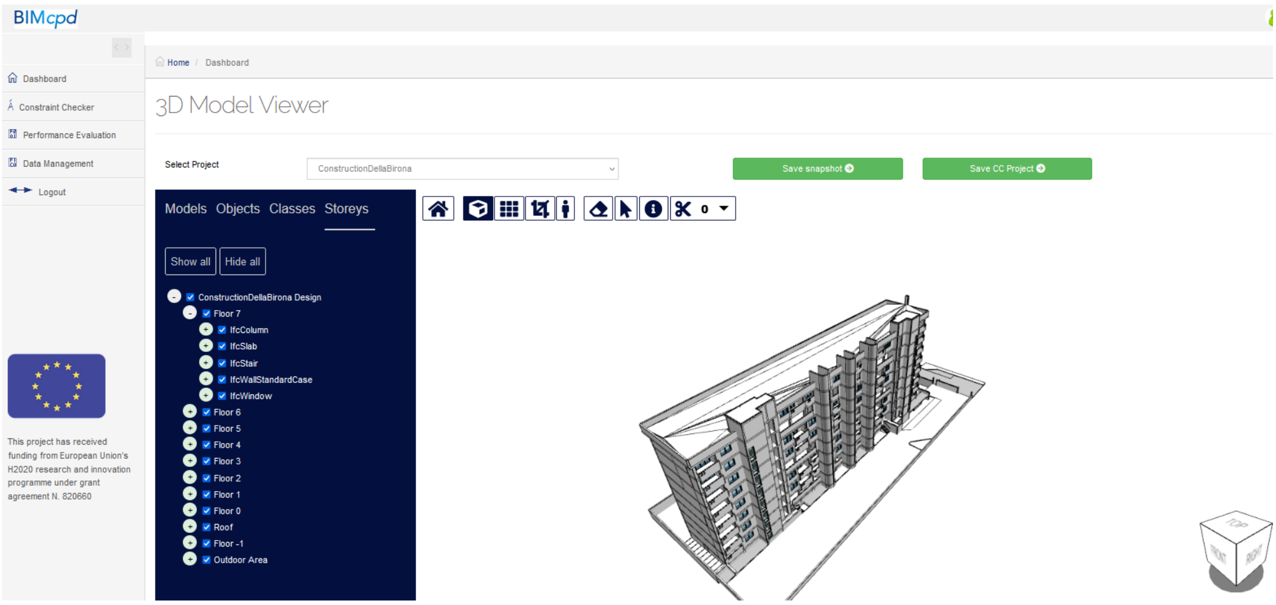


Figure 35 - BIMcpd 3D Model Viewer of the Italian demo site

3.2.6 BIMPlanner Demonstration process

The BIMPlanner tool demonstration started with five remote workshops (30.3., 7.4., 14.4., 29.4. and 12.5.2021) with attendees from Polimi, Regione Lombardia, ALER and VTT. In the workshops the construction planning method was introduced (Location-based management system), that is applied in BIMPlanner and the functionality of the tool. In the workshops scenarios were tested, and initiated planning tasks which continued between the workshops. After the series of workshops, Polimi supported ALER employees to start input the real planning data into the tool and later provide the actual status data of the planned activities. After some testing and further communication with partners, the active demonstration period started at the beginning of July 2021.

The initial master schedule prepared by ALER contained a total of 33 activities with scheduled timing. This master schedule was imported into BIMPlanner to set targets for detailed planning. In the BIMPlanner demonstration, 16 master activities were planned with detailed timing in work locations. Some master activities were also divided in sub activities for detailed planning. Other master activities were left out of the demonstration as those were not critical for site management and could be managed with master scheduling.

In BIMPlanner the detailed scheduling was done by setting the timing for an activity or a sub-activity separately for each predefined work location. The work locations are defined in a specific user interface where the user link selected BIM-objects to the work location to indicate where in the building the work phases will be implemented. For internal construction activities, the work locations were defined as a collection of spaces, mostly representing apartments. For the external activities, the work locations were defined with other BIM-objects, like external walls in the example of Figure 36. The work location definitions are an important part of the planning as those set the level of detail for scheduling and tracking of activities. In the demonstration, ALER created and tested alternative scenarios for the division of the work locations.

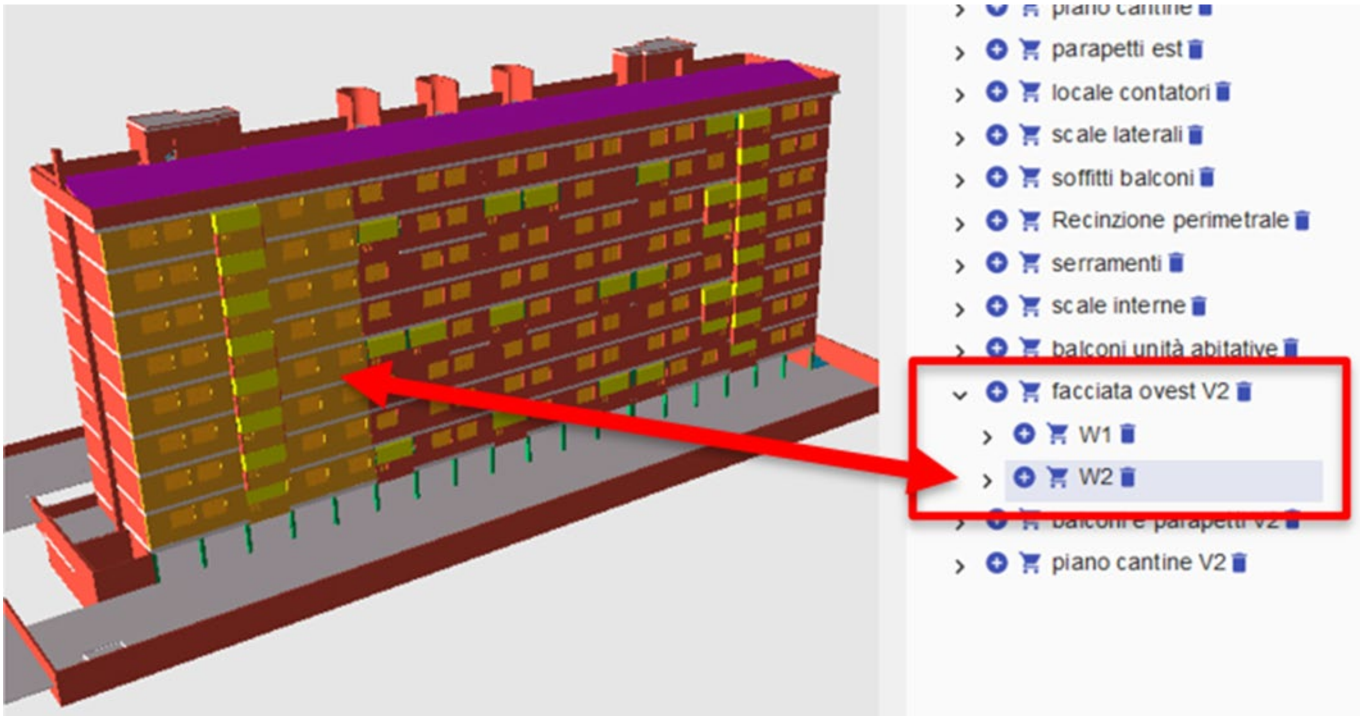


Figure 36 - Example of BIM-based definition of a work location (W2)

During the demonstration, the planning and tracking data were input bi-weekly except during the holiday periods. The data input was done by ALER and communicated with the main contractor to have real planning and site status data and to make an impact on-site management. In Figure 37 is an example of the detailed plan and actual implementation of a façade renovation activity.

Some external disturbances were encountered in the demonstration project (see details in Table 13) which influenced in tool testing. The scheduling needed more changes than expected, requiring more manual rescheduling and the tool had limited functionality for this. Due to the external delays, the BIMPlanner demonstration continued until February 2022.

Additional demonstration activities about the negotiation process between the inhabitants and the construction company through the use of the tools developed (BIMMS, BIMPlanner, BIM4Occupants workflow) is described in detail in chapter 3.2.4.2.

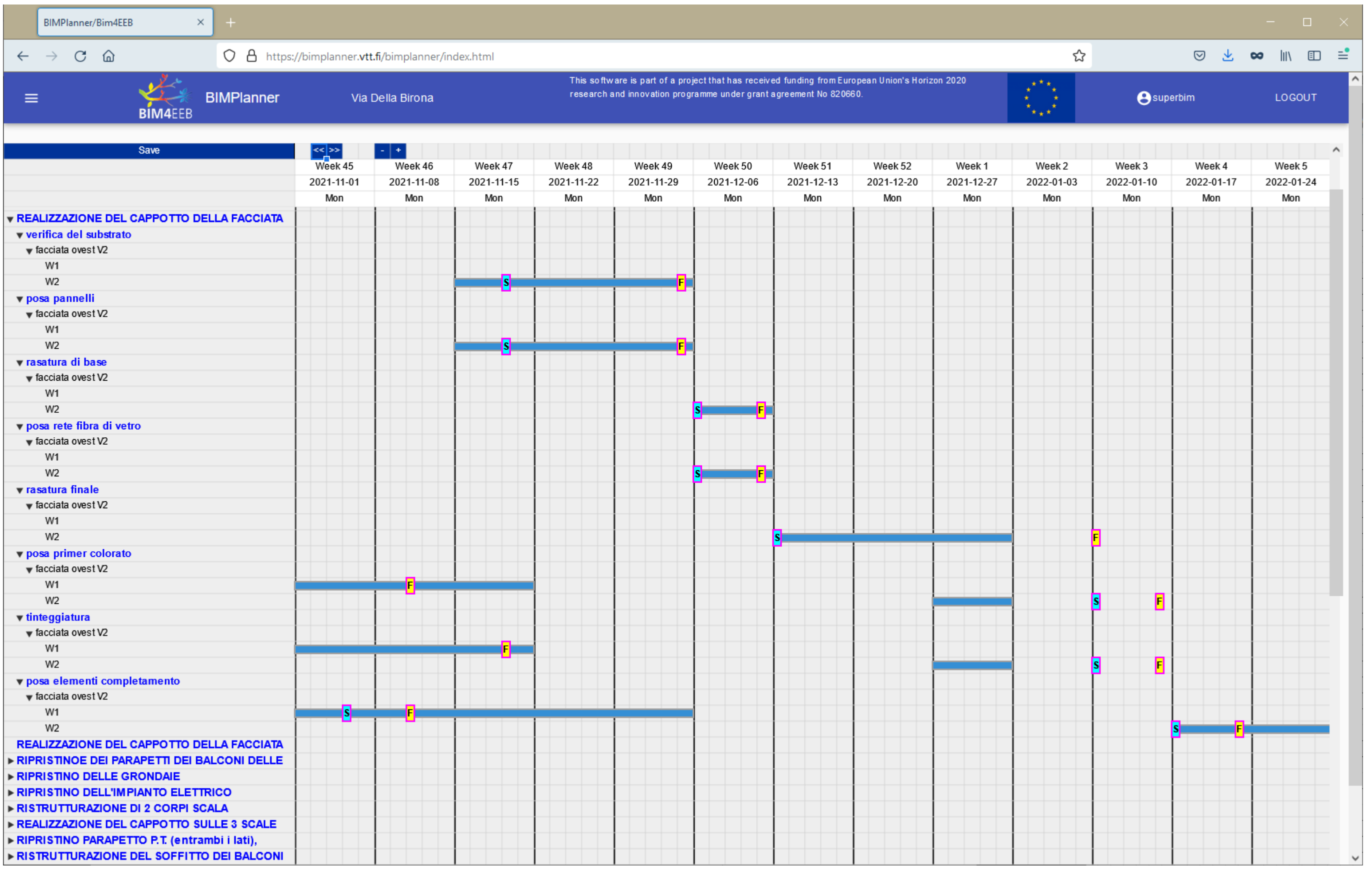


Figure 37 - Example of planned and tracked timing of an master activity (REALIZZAZIONE DEL CAPPOTTO DELLA FACCIATA OVEST) and given sub activities (e.g. verifica del substrato facciata ovest) by work locations (e.g. W1). The blue Gantt bars represent the plan and "S" is the tracked Started date and "F" is the Finished date.

3.3 Final workshop

On January 19th 2022 the Italian workshop on the Italian demo case was held in Milano, Palazzo Lombardia, Piazza Città di Lombardia in the Auditorium Giovanni Testori. In addition to the purpose of dissemination, the workshop had a moment of demonstration of the tools developed within the project and has been organized in two languages, Italian and English simultaneously.

Among the participants, there were representatives of the world of institutions, technical and associations.

Moreover, the project officer was at the end of the first part before the partner intervention. In online and in person conferences all the tools have been presented by partners, after two sessions including institutional greetings and an overall presentation of the BIM4EEB Project. The workshop was mainly targeted to the stakeholders of the Italian pilot site and the advisory board of the project. However, the invitation was also shared publicly through newsletters, websites and Social media (Twitter, Facebook and LinkedIn). A streaming connection, in both Italian and English language, was ensured for the entire duration of the event and the registration was made available on the events site of Regione Lombardia, to maximize the availability of the event. A media partner was selected to foster the communication, such as providing some interviews during, and the end of the workshop.

A survey was available during the workshop and is still available on the website.

The aim was to survey all participants and in particular those who qualified as designers or facility managers based on the toolkit developed in the BIM4EEB Project.

A total of 30 responses were collected among a total of 36 people in attendance and 318 online accesses during the session (of which 206 Italian, 112 International). The collected results are presented in section 6 as a result of the Social KPIs assessment.

The detailed description of the workshop, such as the list of the participants and the meeting agenda are described in D10.12 Demonstration workshops (deliverable in development).

Figure 38 - The Auditiorium Giovanni Testori, Regione Lombardia Building before the beginning of the workshop.

4 Primary KPIs Assessment

Primary KPIs are illustrated in the following chapters. The complete list is in (Annex II – List of the KPIs), additional complimentary analyses about costs and times are present in ANNEX III.

4.1 Renovation process indicators

4.1.1 REP 1 Renovation Time Reduction

4.1.1.1 Introduction

Renovation time reduction (REP 1) is a KPI measuring the time saving performed during the renovation process based on the better management of the renovation activities. It is compared to the baseline/traditional process. A multi-vectored analysis should be considered addressing the different steps of the renovation process (e.g., audit time, data retrieval, renovation actions etc.).

The KPIs will be measured in the Italian demonstration site in relation to each developed BIM-based tool except for BIM4Occupants (BIM4EEB, 2019b).

4.1.1.2 Assessment methodology and baseline calculation

In this context, the main objective is to provide a time and cost baseline for the construction site of Via della Birona, supported by statistical evidence regarding previous interventions on buildings that are characterised by similar features. The baseline for the time reduction assessment has been defined considering a database provided by Regione Lombardia. This database collects the main information that Regione Lombardia, as the owner of the regional building stock for social housing, through ALERs, and as co-financer of several funded programmes for realizing, renovating, refurbishing or retrofitting public houses. The database has been kept to check and track some important stages of the building process. It contains more than 2000 records that were analysed in order to identify a robust baseline to be considered to compare common duration and costs of renovation processes with those accomplished in the Italian demo site.

Table 11 N. of interventions with costs in the range between 800.000 -1.500.000 € and n. of apartments from 30 to 70

Funding programme	n° of interventions similar to via della Birona	Average renovation costs	Average n° of apartments	Average duration of renovation (days)
MIERP[1]	7	€ 1.237.146,63	46	643
SIGI	5	€ 1.070.639,56	13	716
CDQ2[2]	13	€ 1.033.902,04	35	1416
PREC[3] PRU[4] 2CDQR[5]	1	€ 1.822.121,86	56	274
AVERAGE		**€ 1.290.952,52**	**37**	**762**

[1] Edilizia Residenziale Pubblica, at present named Servizi Abitativi Pubblici (SAP)
[2] Programma Nazionale Contratti di Quartiere II
[3] Programma Regionale Emergenza Casa
[4] Programma di Recupero Urbano
[5] 2° Programma Regionale Contratti di Quartiere

Considering only those interventions with costs and n. of apartments similar to those of the Italian demo site (costs in the range between 800.000 -1.500.000 € and n. of apartments from 30 to 70), a first analysis has shown that the average duration of renovations is commonly longer than 1 year and a half, frequently longer than 3 years and a half, with an average duration of 2 years (see Table 11).
Among these, the attention was focused on a few renovations that were very similar to the ones undertaken in the italian demo site, and these buildings have been considered to create the baseline for time reduction assessment (see Table 12).

Table 12 Selection of renovations similar to the interventions undertaken in the Italian demo site (extraction of starting/finishing days and duration of renovation works)

ID	Country	N. flats	Starting day of renovations works			Finishing day of renovations works			Duration of renovation works			
			Scheduled	Effective	Days of delay	Scheduled	Effective	Days of delay	Estimated	Effective	Difference (days)	Difference (%)
CDQ11	Sesto San Giovanni	23	23/10/2006	23/10/2006	0	30/09/2008	20/03/2009	171	708	879	171	24%
CDQ12	Sesto San Giovanni	22	23/10/2006	23/10/2006	0	30/09/2008	23/03/2009	174	708	882	174	25%
CDQ13	Sesto San Giovanni	20	30/09/2007	01/01/2008	93	28/02/2009	01/01/2012	1037	517	1461	944	183%
CDQ14	Sesto San Giovanni	23	01/03/2007	31/05/2007	91	28/02/2009	25/06/2010	482	730	1121	391	54%
CDQ21	Cinisello Balsamo	71	01/09/2007	22/11/2007	82	31/12/2009	24/04/2012	845	852	1615	763	90%
AVERAGE					**53**	**-**	**-**	**542**	**703**	**1192**	**489**	**75%**

As shown in Table 12, in Italy renovations similar to the ones undertaken on the Italian demo site usually have an average of 53 days of delay on the starting date, an average of 542 days on the finishing date, with a mean estimated duration of 703 days there is an average of 489 days of delay and this means a 75% of increase of renovation durations due to such delay.

This means that the duration of renovation in the Italian demo (i.e. 299 days) was lower than 50% of the duration of similar interventions.

The scheduled starting for the Italian demo site in via della Birona was planned for October 6th 2020 and works were effectively started on the scheduled day. Thus, despite the pandemic, there was no delay on the starting day. The careful scheduling that has been adopted within BIM4EEB project has helped to start sharp time renovation works.

During the first 6 months, renovation activities were carried out without interruptions and according to the time schedule. Unexpectedly, the COVID-19 pandemic has introduced further complications, in addition to those due to the total lockdown in spring 2020 that, as demonstrated, could be effectively faced. The first kind of complication was the more difficult management of workers due to contemporary infections from COVID-19 and the consequent quarantine. In the BIM4EEB Italian demo site, this brought only a 15 days break.

The second complication, which has totally frozen the Italian construction market for several months, was due to an extraordinary measure introduced by the Italian Government with a decree of 19 May 2020 to provide factual help to the Italian construction industry to face the consequences of the pandemic itself. This extraordinary measure is called “Superbonus 110%” and it offers a deduction rate of 110% on certain expenses related to energy efficiency or other anti-seismic improvements during renovations. This measure, which has eliminated renovation costs for some energy efficiency interventions, inevitably has led to an enormous demand for insulating materials, façade cladding products, plasters, windows, external doors, and HVAC systems.Also, the Italian demo site in via della Birona has faced the consequences of such extraordinary measure and this led to some partial or total interruptions in renovation works that have been summarized in Table 13.

Table 13 Overview of the extraordinary breaks in renovation works due to COVID-19 pandemic and COVID-19 related measures

Extraordinary breaks in renovation work due to COVID-19 pandemic and COVID-19 related measures undertaken by the Italian government	Expected end of work	Extension			Reason
		from	To	n. days	
1st-time extension of 15 days for work suspension due to Covid workers	16/08/2021	19/04/2021	04/05/2021	15	Covid-19
2nd-time extension of 67 days for a partial suspension of works (façade cladding suspended) due to delayed supply of EPS panels and suspension of the laying of the plaster façade coat due to the delayed supply of façade render	21/10/2021	15/06/2021	01/09/2021	78	delayed supply of EPS panels and façade render
Extension time allowed for continuous delays in the supply of materials	28/02/2022	21/10/2021	28/02/2021	130	delayed supply of EPS panels and raw materials (extruded profiles) for doors and windows
3rd time extension of 24 days for a partial suspension of works due to delayed supply of roller shutters	24/03/2022	01/02/2022	25/02/2022	24	delayed supply of roller shutters
TOTAL EXTENSIONS ARE NOT TO BE CONSIDERED BECAUSE COVID-19 RELATED				**247**	

4.1.1.3 Results

In the assessment of REP1 the effects of these two completely extraordinary circumstances should not be repeated because they entirely depended on the pandemic; thus they have not to penalize the calculation. That is the reason why in the following table the duration of renovation works in the Italian demo site has been calculated to rule out the impacts of the pandemic situation.

Table 14 Duration of renovation works in the Italian demo site in via della Birona

ID	Country	N. flats	Starting day of renovations works			Finishing day of renovations works			Duration of renovation works			
			Scheduled	Effective	Days of delay	Scheduled	Effective	Days of delay	Estimated	Effective	Difference	
											(days)	(%)
VIA DELLA BIRONA	Monza	65	06/10/2020	06/10/2020	0	01/08/2021	24/03/2022	235	299	287	-12	-4%
*** without considering the delay due to pandemic situation and supply delay, the effective duration of 536 days has not to be decreased by the total extensions due to covid-19 related, i.e. of 236 days (see Table 13), thus (534-247) days = 287 days**												

As a consequence, as declared in the Grant Agreement (see Obj 1.1: Renovation working time reduction) the application of BIM4EEB on the Italian demo site has demonstrated a decrease of at least by 20% from the baseline, decreasing the time of disturbance experienced by the inhabitants of renovated buildings. Specifically, comparing the 0% in the last column of Table 14 with the percentages in the last column of Table 12 (the interventions used as a baseline) it is evident that the reduction of renovation working time has been at least **(24-(-4))%=28%.**

4.1.2 REP 2 Renovation Cost Reduction

4.1.2.1 Introduction

With the Obj 1.2: Renovation costs reduction" declared in the Grant Agreement the KPI REP 2 is intended to measure the average cost of renovation in order to check if BIM4EEB has reduced it by at least 15%. The use of integrated processes developed by BIM4EEB is aimed not only at triggering important cost savings during renovation design and realisation but also in all other phases of the building life-cycle. This is possible thanks to improved accuracy and to higher attention to the quality of the construction phase process with the subsequent reduction of unexpected variations or complete construction suspensions and of re-works costs.

4.1.2.2 Assessment methodology and baseline calculation

With this in mind, the same interventions similar to the Italian demo sites that were considered for the time reduction assessment (Table 12) have been also used for the costs reduction assessment. In Table 15 the indication of their costs is provided with the calculation of the difference between their estimation and their actual increase during renovation works themselves.

Table 15 Selection of renovations similar to the interventions undertaken in the Italian demo site (extraction of costs)

ID	Country	N. flats	Costs			
			Estimated	Effective	Increase [€]	Increase [%]
CDQ11	Sesto San Giovanni	23	€ 747.886,95	€ 849.543,00	€ 101.656,05	14%
CDQ12	Sesto San Giovanni	22	€ 766.034,41	€ 813.613,00	€ 47.578,59	6%
CDQ13	Sesto San Giovanni	20	€ 736.882,00	€ 736.882,00	€ 0,00	0%
CDQ14	Sesto San Giovanni	23	€ 771.803,73	€ 848.502,00	€ 76.698,27	10%
CDQ21	Cinisello Balsamo	71	€ 829.450,33	€ 945.263,00	€ 115.812,67	14%
AVERAGE					€ 68.349,12	9%

As shown in Table 15 for similar interventions, there were increases in costs by up to 14%.

4.1.2.3 Results

In the italian demo site, no increase in costs has been tracked (see Table 16) a decrease of up to 28% has been reported.

Table 16 Costs of renovation works in the Italian demo site in via della Birona

ID	Country	N. flats	Costs of renovation works			
			Estimated	Effective	Decrease [€]	Decrease [%]
VIA DELLA BIRONA	Monza	65	€ 1.594.654,81	€ 1.146.008,74	€ 448.646,07	28%

4.2 Comfort Indicators

4.2.1 COM 7 Occupancy Profiling Accuracy

4.2.1.1 Introduction

The KPI Occupancy profiling accuracy measures deviations related to actual and predicted occupancy schedules.
Occupancy status refers to the level of occupancy in the building environment (actual/planned). Which will result as deviation percentage. Accuracy is calculated from deviation.

4.2.1.2 More details about this KPI and the calculation process are presented in D3.5 (BIM4EEB, 2019b). This KPI is associated with the demonstration of the BIM4Occupants tool and the capability of collecting users' feedback in order to have a fine-grained occupancy profiling estimation.Assessment methodology and baseline calculation

As indicated also in the introduction section and in D3.5 the key point is to estimate the values of actual and planned occupancy.

In the context of the project, planned occupancy is defined as the occupancy related to the design phase of the building where predefined schedules (as stated also in the standardisation) are considered. On the other hand, actual occupancy reflects the actual situation in the building environment.

It is evident that one size does not fit all cases and thus the predefined schedules, though representative enough at an average level, do not address the particularities of each case scenario (building environment).

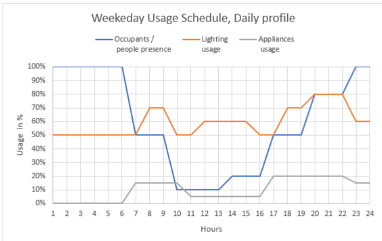
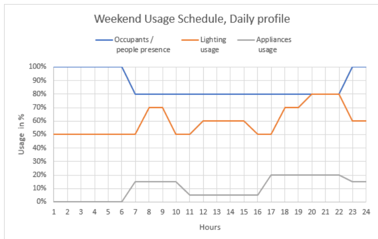
Towards this direction, the main innovation and actual contribution of the BIM4Occupants framework is to facilitate more accurate estimation of the occupancy level in the building environment. There are two main processes considered in the project:

a) End users through the BIM4Occupants are prompted to provide their feedback about the occupancy level in the building environment. This configuration process should reflect the actual situation in the building environment and thus the users can properly define the occupancy states. Temporal deviations over time (e.g., seasonality patterns, etc.) are also addressed by the tool as we are able to track the history of information provided by the users. More details about this functionality available in BIM4Occupants is provided in D7.2 (BIM4EEB, 2021g).
b) Complementary to the BIM4Occupants occupancy logging process, occupancy measurement data are also considered in the analysis (in case occupancy related data are available). As reported in D6.7 (BIM4EEB, 2020c), occupancy presence data may be cross-correlated with the manually defined profiles to extract fine-grained occupancy profiles for each building area. We have to point out that this second approach is applied in the project to a limited number of building zones (once again considering the installation of sensors and the logging capabilities of the sensing equipment available in place).

By taking into account the aforementioned parameters, the KPI calculation is performed.

As stated in the previous section, a preliminary step of the methodology is the definition of baseline (planned occupancy) values. The reference occupancy schedule parameters for the Italian demo site are provided by the demo partner as part of the preparatory activities of the project (reflecting the configurations provided by building simulation tools). The extrapolation of these data to the selected building apartments is performed and thus the indicative occupancy schedule in aggregate is presented in Table 17.

Table 17 indicative occupancy schedule

Apartment ID	No of Occupants	Occupancy Configuration (60% presence)
apartment_C	1	Average occupancy per apartment: 1.6 Occupancy time schedule (ISO 17772-1) (ISO International Standard, 2017) Weekdays  Week end 
apartment_A	2	
apartment_I	5	
apartment_G	3	
apartment_H	1	
apartment_E	1	
apartment_D	1	
apartment_F	2	
apartment_B	1	
apartment_N	3	
apartment_L	3	
apartment_O	1	
apartment_M	2	

Then, input data as provided by the occupants to the app were considered in order to fine-tune the information about actual occupancy at building premises. The input was provided during the registration phase, and then users were prompted (via communication activities performed by the demo leaders) to update the parameters provided about occupancy (if needed).

A statistical analysis over the input data of the users is provided in order to specify the predicted occupancy level in building premises. In the following figure, we present the results of the analysis for Apartment – A and Apartment – H on weekdays and weekends.

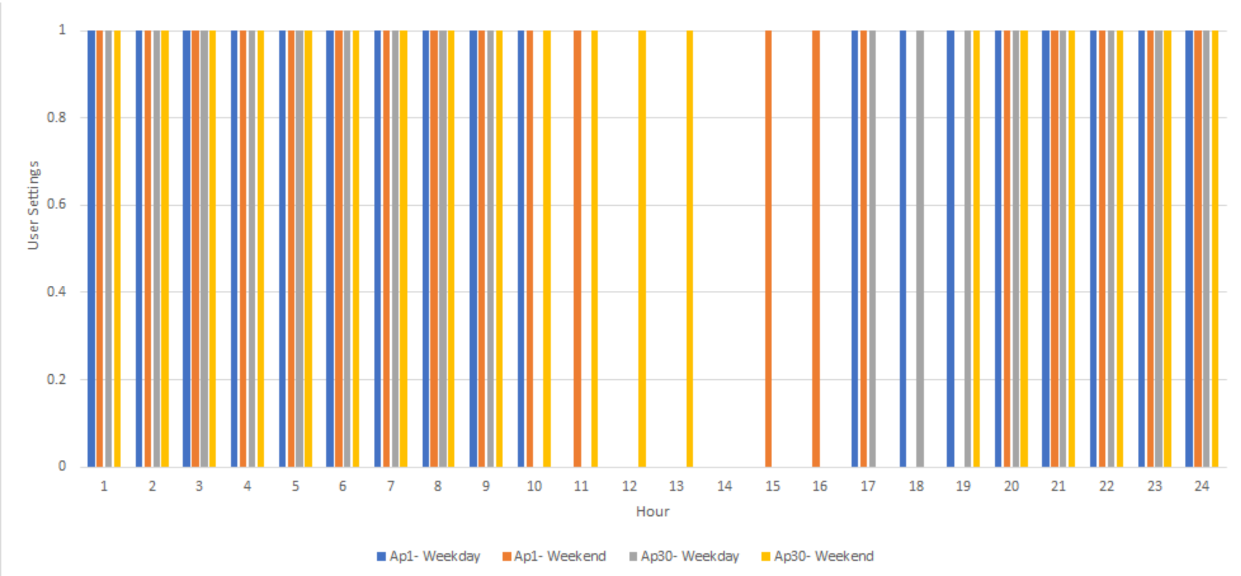


Figure 39 - Occupancy Profiling User Settings

4.2.1.3 Results

Last not least, and in order to evaluate the accuracy of occupancy profiling methods defined in the project (input settings by buildings occupants), actual occupancy presence data is considered. Presence data were partially available at IT building apartments (5 in total) and thus further analysis was performed over motion events in order to extract the actual occupancy profiles. A statistical analysis over the occupancy event data (resampling of the event data) is performed in order to have time series of occupancy at the time granularity agreed in the project – hourly level applies and then statistics over the data streams are performed in order to extract the typical occupancy presence profile during weekdays/weekends. Indicative results of this analysis are presented in the following figure for Apartment – A and Apartment – H. (We exclude from the analysis night hours 24.00 – 07.00 as there are no presence events reported from the sensing equipment installed in premises).

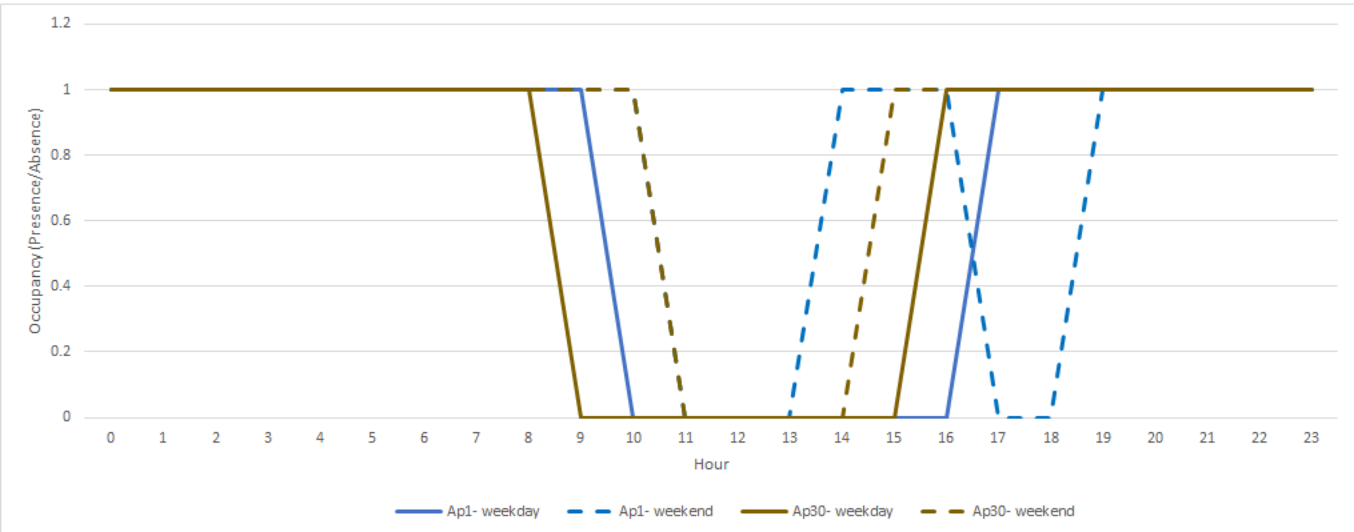


Figure 40 - Occupancy Profiling – Presence data

Last but not least, the KPI Occupancy profiling is calculated at the IT demo site for the demo premises where actual metering data were available. Overall, the accuracy level is **89.76 %** considering that the building occupants were motivated to periodically fine-tune occupancy related information at the dedicated application (in contrary to the ISO-based data comparison with actual data where the accuracy level is 83.33%)

4.3 Energy Performance indicators

4.3.1 ENE 3 Primary energy savings

4.3.1.1 Introduction

Within the objectives declared in the Grant Agreement, the KPI ENE 2 is intended to measure the primary energy savings to check if BIM4EEB has reduced it by at least 10%. The renovation activities focused on the improvement of the winter performance of the building. The primary energy was then computed considering only the heating service, as the building renovation interventions have influenced only this type of demand. Any other primary energy consumption is therefore considered invariant.
The KPI Primary energy savings calculates the percentage difference between measured and baseline primary energy consumption data within a predefined period.

4.3.1.2 Assessment methodology and baseline calculation

In this section, a description of the assumptions made to normalise the primary energy saving is presented. Because outdoor temperatures vary between the years and months the results of the energy consumption are presented in the normalised weather of Cinisello weather station (Figure 41), which is the nearest weather data source to the Via Birona building. The normalising will enable the comparison of the data of the heating season 2021-22, in which the energy retrofit was concluded, with the reference heating year assumed as the season 2019-2020, before the renovation started.

Table 18 presents the monthly heating degree days (HDD) used in the normalising process.

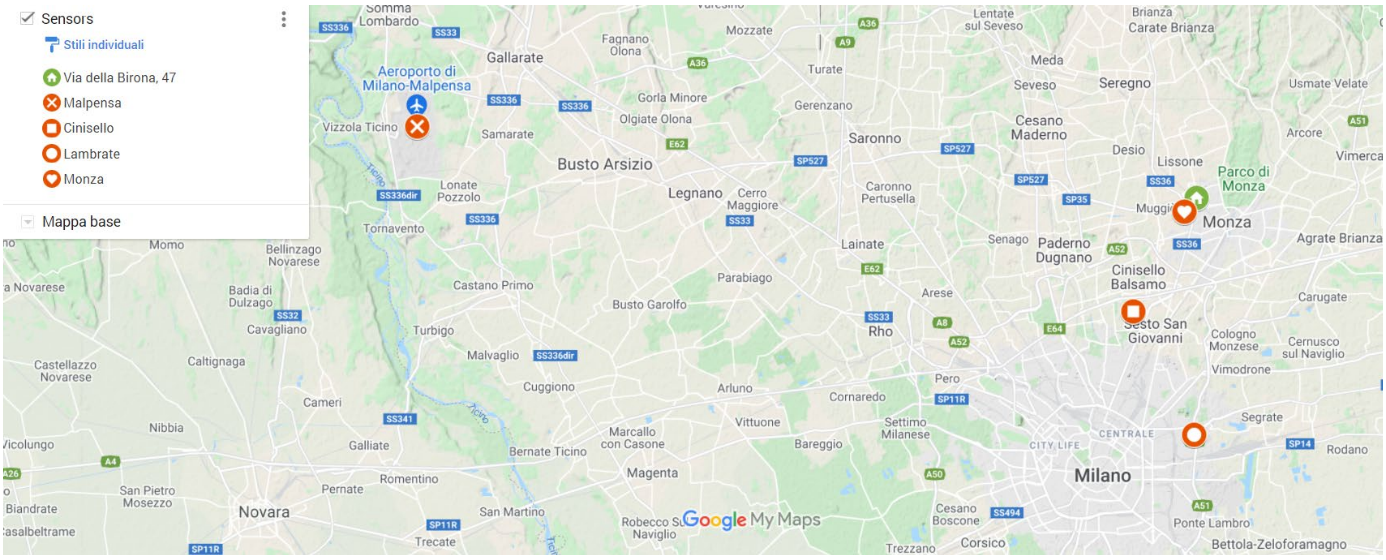


Figure 41 - Location of the simulation weather data (Malpensa) and the Cinisello weather station for the standardised representation of energy consumption.

Table 18 The HDD data of the weather data (Milano Malpensa airport) in IDA-ICE simulator, standard UNI 10349 year and baseline year of the Via Birona realised consumptions (heating season 2019-20).

Month	HDD 18 (Milano Malpensa in IDA-simulator)	UNI 10349 HDD18 Cinisello	Cinisello heating season 2019-20 (baseline measurement period)	Measurement period after renovation Oct 2021 - Jan 2022
1	541	467	458	476
2	449	370	308	307
3	317	311	286	---
4	205	101	122	---
5	82	0	13	---
6	31	0	6	---
7	4	0	0	---
8	5	0	0	---
9	62	0	12	---
10	173	114	95	168
11	350	260	274	293
12	482	472	385	475
Year	**2,702**	**2,095**	**1,959**	**---**

The measured energy demand for the heating season 2019-2020 was considered as a baseline for the calculation.
At the time of writing this report, the measured energy demand after the renovation ranges from October 2021 to January 2022. A reduced heating season will be then considered for the evaluations. All the measured values are normalized before in accordance with the Heating Degree Day (HDD) correction.
All the data are collected through the energy bills. The applied conversion factor is 39.25 MJ/m^3.
The primary energy factors (PEF) for Gas is 1.05, in accordance with the table reported in Annex 1 Italian Interministerial Decree of 26 June 2015 - Application of energy performance calculation methodologies and definition of prescriptions and minimum requirements for buildings [Ministro dello sviluppo economico, 2015].
The installation of insulation in the main facades and the replacement of windows and doors was completed by the end of 2021. It is expected that this may have led to some variation in the results and is estimated that the reduction in demand may be even greater in the next years.

Table 19 Monthly Primary energy consumption before the renovation. Reduced heating seasons from October to January.

Month	Baseline 2019-20 (kWh)	Baseline 2019-20 HDD Correction (kWh)	Baseline 2019-20 HDD Correction Primary energy (kWh)
Oct 2019	56,782	68,138	**71,545**
Nov 2019	109,298	103,865	**109,058**
Dec 2019	129,889	159,157	**167,115**
Jan 2021	133,829	136,608	**143,439**

Table 20 Monthly Primary energy consumption after the renovation. Reduced heating seasons from October to January.

Month	After Renovation 2021-22 (kWh)	After Renovation 2021-22 HDD Correction (kWh)	After Renovation 2019-20 HDD Correction Primary energy (kWh)
Oct 2021	34,827	23,590	**24,770**
Nov 2021	69,751	61,874	**64,968**
Dec 2021	99,143	98,621	**103,552**
Jan 2022	105,379	103,365	**108,533**

4.3.1.3 Results

The primary energy savings, calculated comparing the years 2019-20 and 2021-22 is **38%**. A reduced heating season (October to February) is considered in accordance with chapter 4.3.1.2.

Table 21 Primary energy savings. Reduced heating seasons from October to January.

Total primary Energy Consumption for heating BEFORE the renovation (PER_E) (Oct 19 – Jan 20) – HDD Corrected (kWh)	Torimary Energy Consumption for heating AFTER the renovation (PES_C) (Oct 21 – Jan 22) – HDD Corrected (kWh)	Primary Energy Savings (PES) [%]
490,392	303,970	**38**

4.3.2 ENE 4 Energy performance accuracy

4.3.2.1 Introduction

The KPI energy performance accuracy measures the deviation between predicted and actual energy use by comparing predicted and real energy consumption, which will result as deviation percentage. Accuracy is calculated from deviation.

4.3.2.2 Assessment methodology and baseline calculation

In this section, a description of the assumptions made in the building energy modelling phase is presented. The output of this work is the calibrated energy model of the demonstration site, a fundamental element of the demonstration of KPIs. The main element of the ENE 4 KPI calculation was to evaluate the measured and simulated gas consumption, to which the reduction impact of the outside wall and window renovation mainly applies. The normalisation procedure was equal to Chapter 4.3.1.2

The baseline calculation of Via Birona building was calibrated to match the realised consumption by comparing the actual gas consumption of the heating season 2019-20 and the simulated gas consumption - both normalised to the Cinisello weather to enable the transparent comparison. The model was built based on the IFC-data delivered by partner ALER. Further details related to the digital built-up process of the Via Birona baseline model are presented in D 6.9.

The structural input data of the baseline simulations are presented in

Table 22.
The baseline building was assumed to have a ventilation rate of 0.5 l/s,m², which corresponds to the air change rate of 0.67 1/h. This is a good assumption of an old, somewhat leaky, building. The windows of the building were mainly single-glazed, but there were noticed some units of double-glazed windows during the audit visits. The overall assumption was that 90% of the windows were single glazed and 10% double-glazed. The set point temperature of the indoor climate in the apartments was 23 °C, which is based on the audit visit observations before the renovation.
The internal loads and the profile (lighting and appliances) were assumed to be the same that (Causone et al., 2019) has studied in Italy resulting in average consumption of 27 kWh/m²,year. The daily electric profile used in the simulations is presented in Figure 42. All day types (weekday, weekend) had the same profile in the simulations. The modelled number of people living in the building was 156 in 65 apartments and the average presence at home was 60% of the time. The average size of the apartment was 73 m².

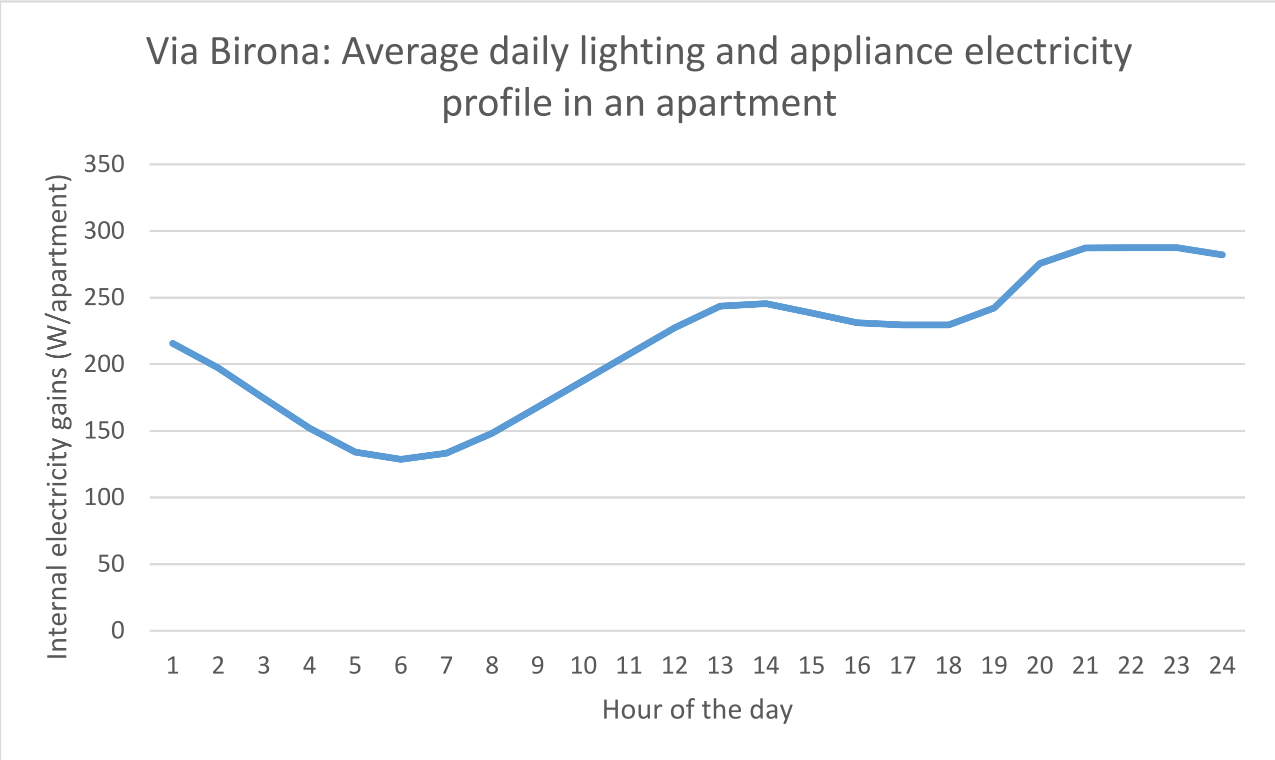


Figure 42 - The average appliance and lighting energy profile (Causone 2019) used in Via Birona simulations

Table 22 The structural input data of the baseline simulation model

		Input data Report	
Project		**Building**	
Via Birona apartment building from 1980's. Baseline case has no structural renovations done. A gas boiler for space heating. No space cooling. T_{indoor} = 23 °C. Exact values are not known. No existing measurement before the renovation started. Elderly people living, prefer higher indoor temperatures. Iterated the ventilation 0,5 l/s,m2 in living spaces and infiltration to match the simulation to the measurements for the heating season 2019-2020. Data used for the KPI calculations		Model floor area	4534.1 m^2
Customer	ALER	Model volume	12067.2 m^3
Created by	Jari Shemeikka, VTT	Model ground area	0.0 m^2
Location	Milano/Malpensa_160660 (ASHRAE 2013)	Model envelope area	5265.7 m^2
Climate file	Milan_ASHRAE	Window/Envelope	15.3 %
Case	Baseline Via Birona Monza	Average U-value	1.51 W/(m^2 K)
Simulated	11.03.2022 14.15.22	Envelope area per Volume	0.4364 m^2/m^3

		Fixed infiltration airflow rate	146.272 l/s	
Building envelope	**Area [m^2]**	**U [W/(m^2 K)]**	**U*A [W/K]**	**% of total**
Walls above ground	**2,751.59**	**0.75**	**2,061.34**	**25.93**
IT Masonry outside wall 1980's	2,745.78	0.75	2,054.00	25.84
Walls below ground	**0.00**	**0.00**	**0.00**	**0.00**
Roof	**817.60**	**0.85**	**691.50**	**8.70**
IT Upper floor concrete	224.09	1.10	245.80	3.09
IT Upper floor concrete 1980's	593.51	0.75	445.70	5.61
Floor towards ground	**0.00**	**0.00**	**0.00**	**0.00**
Floor towards amb. air	**807.85**	**0.99**	**798.60**	**10.05**
IT Slab on ground	807.85	0.99	798.60	10.05
Windows	**804.69**	**4.97**	**3,999.32**	**50.31**
Mixed 90% single, 10% double	804.69	4.97	3,999.32	50.31
Doors	**84.00**	**2.09**	**175.80**	**2.21**
IT external door U value 2.1	84.00	2.09	175.80	2.21
Thermal bridges			**222.37**	**2.80**
Total	**5,265.73**	**1.51**	**7,948.92**	**100.00**

The comparison of the simulated and realised consumption in HDD-monthly energy plot is presented in Figure 43, which shows good correspondence between the simulations and the actual measured consumption. The fit line of the data points presents the linear dependency of the monthly consumptions and monthly HDD-values. The closer the data points are to the linear fit the better correspondence the building has in relation to the outside temperature. The energy behaviour of the building follows usually the linear fit in case there are no large changes in thermal losses or internal gain contributing to the heating demand.

The deviations respect to the linear line is mainly caused by the solar gains from windows, ventilation habits of residents or possible unideal control of the indoor temperature. Figure 43 shows that the actual measured gas consumption is higher than linear estimate during the spring and autumn (HDD is between

100-250 Kdays/month). This can be a result of high indoor temperature, which can mean overheating because of the manual room temperature control and simultaneously increased window ventilation by the occupants during the heating season to compensate the too hot indoor air.

The residents of the Via Birona building mentioned during the audit visits that from time to time the indoor air temperature feels cold in the apartments. This phenomenon was modelled by limited heating capacity in rooms, which allows the temperature to drop in the model during extreme outside temperatures (e.g., -5 °C).

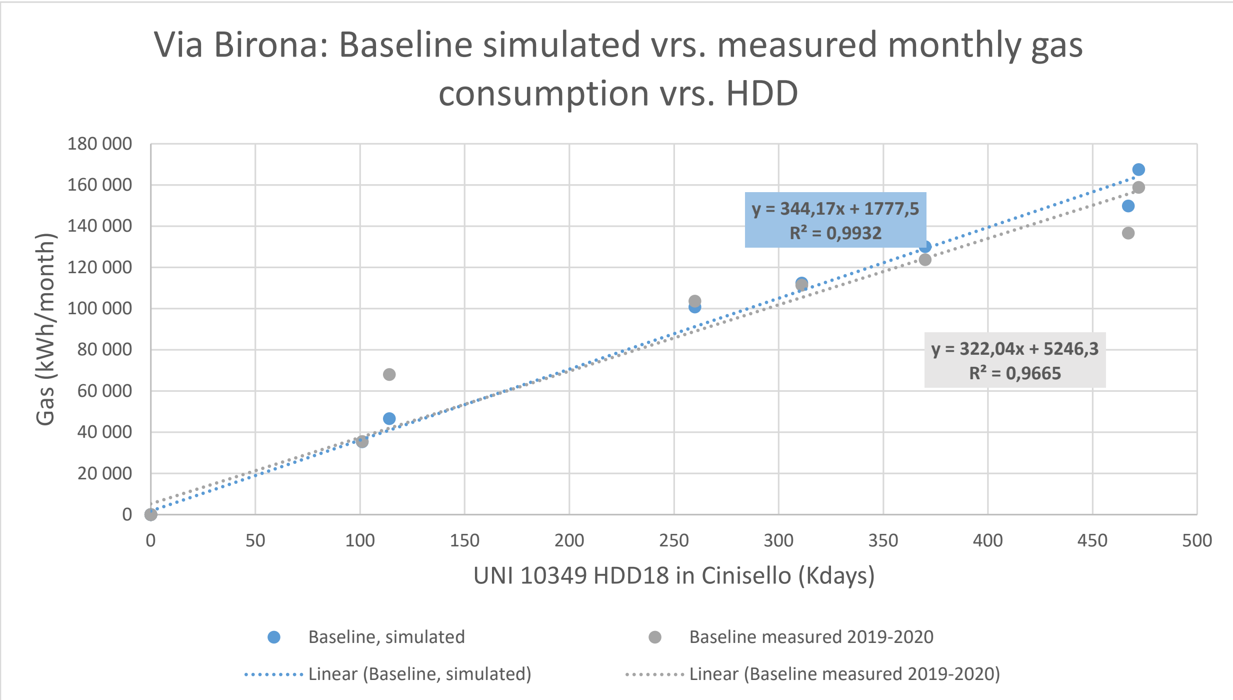


Figure 43 - Via Birona building normalised monthly energy consumption of the calibrated model and the actual consumption on heating season 2019-20 before the renovation

Table 23 Baseline results from IDA simulator. Via Birona model before the renovation actions. The gas consumption is presented in the Cinisello normalised weather.

		Used energy		Peak demand	Cost		Primary energy	
		kWh	kWh/m²	kW	€	€/m²	kWh	kWh/m²
	Lighting	11,948	2.6	1.36	2,700	0.6	28,914	6.4
	Appliances	111,203	24.5	17.33	25,129	5.5	269,077	59.3
	HVAC electricity	11,842	2.6	1.35	2,676	0.6	28,656	6.3
	Gas	742,376	167.4	237.5	41,573	9.4	779,495	175.8

After renovation calculation:
The calculation of the renovation actions used the same energy normalising procedure (Cinisello weather) as the baseline calculation.

The renovation actions for outside walls and windows were added to the baseline model and the results were re-calculated. The internal loads (people and electricity gains), ventilation rate and infiltration were kept the same as in baseline simulations. The indoor temperature setpoint of the apartments was raised from 23 °C to 24 °C in the simulation model. This temperature increase was noticed during the audit visits after the renovation. The indoor temperature increase leads to a small rebound effect, which means the situation when energy efficiency measures provide smaller reductions in the consumption of energy than could be anticipated. Most likely the manual radiator valve control of the room temperature is the reason for this.

Via Birona building renovation had two main energy efficiency measures. Table 25 contains the input data of the structural components in the simulations after the renovation measures have been applied. The renovation measures were:

- Renovating the old masonry outside wall (U-value 0.75 W/m²K) by adding 120 mm insulation + plastering on top of the old wall, resulting in a **new U-value 0.25 W/m²K**
- Replacing the old windows (average U-value 5.0 W/m²K) with more energy-efficient ones, resulted in a new **U-value 1.14 W/m²K**

The energy simulation results after the application of the wall and window measures are presented in Table 24. The simulation results show a **36% reduction** in energy consumption.

Table 24 The applied renovation measure results from IDA simulator. Via Birona model after the renovation actions. The gas consumption is presented in the Cinisello normalised weather.

		Used energy		Peak demand	Cost		Primary energy	
		kWh	kWh/m²	kW	€	€/m²	kWh	kWh/m²
	Lighting	11,948	2.6	1.36	2,700	0.6	28,914	6.4
	Appliances	111,202	24.5	17.33	25,129	5.5	269,077	59.3
	HVAC electricity	11,842	2.6	1.35	2,676	0.6	28,656	6.3
	Gas	477,773	105.4	234.4	26,756	5.9	501,661	110.6

The sensitivity of the simulation results was studied by changing indoor temperature setpoints and air change assumptions in the apartments one by one and simulating the renovated building with a new value. The changes and the respective impact on the gas consumption were:

- Indoor temperature setpoint ± 1 °C resulted in ± 9% change in gas consumption
- Air change ± 10 % resulted in ± 6% change in gas consumption

The **sensitivity study proposes that ±10% accuracy in gas consumption** and respective savings can be expected even though the baseline model could be fine-tuned to correspond to the measured consumption. The largest error source in the energy balance is the ventilation, because of the unknown window opening habits of residents.

Table 25 The structural input data of the simulation model when outside walls and windows are renovated, so called "After" model

Project		**Input data Report**	
		Building	
Outside wall renovation: Insulation 120 mm and plastering - Isolamento termico (120 mm)+new windows U=1,1 W/m2,K and roller shades. Updated the indoor temperature to 24 oC (audit obsevation by Andrea Mainini)		Model floor area	4534.1 m^2
Customer	ALER	Model volume	12067.2 m^3
Created by	Jari Shemeikka, VTT	Model ground area	0.0 m^2
Location	Milano/Malpensa_160660 (ASHRAE 2013)	Model envelope area	5265.7 m^2
Climate file	Milan_ASHRAE	Window/Envelope	15.3 %
Case	All energy saving actions together	Average U-value	0.6644 W/(m^2 K)
Simulated	11.03.2022 14.49.02	Envelope area per Volume	0.4364 m^2/m^3

Fixed infiltration airflow rate 146.272 l/s

Building envelope	**Area [m^2]**	**U [W/(m^2 K)]**	**U*A [W/K]**	**% of total**
Walls above ground	**2,751.59**	**0.25**	**693.24**	**19.81**
IT Masonry outside wall 1980's+120 mm insulation	2745.78	0.25	685.90	19.60
Roof	**817.60**	**0.85**	**691.50**	**19.76**
IT Upper floor concrete	224.09	1.10	245.80	7.03
IT Upper floor concrete 1980's	593.51	0.75	445.70	12.74
Floor towards ground	**0.00**	**0.00**	**0.00**	**0.00**
Floor towards amb. air	**807.85**	**0.99**	**798.60**	**22.82**
IT Slab on ground	807.85	0.99	798.60	22.82
Windows	**804.69**	**1.14**	**917.35**	**26.22**
Pilkington Optifloat Green (6gn-15Ar-S(3)6)	804.69	1.14	917.35	26.22
Doors	**84.00**	**2.09**	**175.80**	**5.03**
IT external door U value 2.1	84.00	2.09	175.80	5.03
Thermal bridges			**222.37**	**6.36**
Total	**5,265.73**	**0.66**	**3,498.86**	**100.00**

4.3.2.3 Results

The monthly results of the baseline simulation and the monthly gas consumption are presented in Table 26. The yearly energy performance accuracy **EPA of the baseline model is 99.4%.** The monthly values show some variations, especially during the spring and autumn time, when the absolute monthly consumption is small. Further details of the baseline simulation assumptions are presented in chapter 4.3.2.2.

Table 26 The energy performance accuracy of the Via Birona baseline. Heating season 2019-2020 before the renovation. Total energy consumption measured (ES_C) and simulated (EB_E)

Realised gas consumption month	**ES_C** Baseline measured 2019-2020 (kWh)	**EB_E** Baseline, simulated (kWh)	**EPA** Energy performance accuracy
Oct 2019	67,988	46,643	68.6 %
Nov 2019	103,636	100,740	97.2 %
Dec 2019	158,807	167,433	94.6 %
Jan 2020	136,608	149,762	90.4 %
Feb 2020	123,687	130,012	94.9 %
March 2020	111,395	112,427	99.1 %
April 2020	35,500	35,358	99.6 %
Year	**737,621**	**742,376**	**99.4 %**

The measurement period after the renovation was between Oct 2021 and Jan 2022. The monthly results of the simulation and respectively measured gas consumptions after the application of the renovation measures are presented in Table 27. The energy performance accuracy **EPA after renovation is 93.9%.** Further details of the renovation simulation assumptions are presented in chapter 4.3.2.2.

Table 27 The energy performance accuracy of the Via Birona after renovation of walls and windows. Measurement period Oct 2021-Jan 2022. Total energy consumption measured (ES_C) and simulated (EB_E)

Realised gas consumption month	**ES_C** Measurement period Oct 2021- Jan 2022 (kWh)	**EB_E** Simulated, walls and windows renovated (kWh)	**EPA** Energy performance accuracy
Oct 2021	23,758	26,616	88.0 %
Nov 2021	62,315	61,467	98.6 %
Dec 2021	99,323	111,468	87.8 %
Jan 2022	104,101	107,702	96.5 %
Oct 2021- Jan 2022	**289,497**	**307,254**	**93.9 %**

4.4 Social KPIs

The social KPIs category has the aim to focus on the user assessment of the BIM4EEB BIMMS platform and the different developed BIM-based tools.

The evaluation process relies on dedicated questionnaires reserved for each BIM4EEB stakeholder such as designers, construction companies and building occupants. It is based on the system usability scale (SUS) approach to establish a method for assessing the BIM4EEB usability among users past the renovation phase (D3.5).

4.4.1 SOC 8 Improved monitoring/access on information during renovation works

Construction companies and occupants were asked how much BIM4EEB project could help in improving their monitoring capabilities for the renovation interventions. SOC 8 is demonstrated by BIMMS, Fast Mapping and BIM4Occupants.
FM/Construction companies and occupants can access easily different kinds of information such as logbook data, BIM models, data streaming, accessing the BIMMS and consequently monitoring different aspects of the renovation.

Through Fast Mapping, users acquire knowledge about hidden elements inside walls (e.g., wall studs, water pipes, and electrical ducts).

In addition, BIM4Occupants supports occupants by having updated information about their apartment's indoor conditions and renovation works. They can monitor the conditions and the renovation works by accessing the mobile application.

4.4.2 SOC 9 Increased easiness in information exchange and tracking (data accessibility)

This KPI wants to investigate how much BIM4EEB improves tracking and information exchange among its FM/Construction Companies, Designer and Occupants.

It is referred to the BIMMS, Fast Mapping, AUTERAS, BIMcpd and BIMPlanner, BIM4Occupants. These tools can make easier to exchange the information and tracking by digitalising the data and providing them with a common data environment.

4.4.3 SOC 10 Modular design and development of the BMS platform

SOC 10 aims at estimating how much the modular design of BIM4EEB makes it easier to address other types of requirements from the various business actors.

The BIMMS platform and repository offer the connection among the several different developed tools and in addition, each instrument within the BIMMS has its own function and it can work independently.

4.4.4 SOC 11 Interoperability and data storage capability of BMS platform

SOC 11 is related to the BIM4EEB ability to guarantee interoperability among the different tools and data storage capability of the platform.

This is offered by BIMMS. The platform collects all the data coming from the building and connects the developed BIM-based tools.

4.4.5 SOC 12 Use of BIM in renovation business

The use of BIM within the renovation context can be a means to overcome financial and technical barriers common in renovation projects as well as improve energy savings.

Fast Mapping toolkit, even if it cannot create currently the whole BIM model, it may be used to verify the positions of structures that have been modelled in other ways. Designers can be supported in the use of

BIM in renovation business by BIMeaser thanks to its quick development.

4.4.6 SOC 13 Use of dynamic simulation tools for energy assessment

SOC 13 refers to the use of BIM enriched models that can encourage the renovation market but also increase the quality of design. The KPI is demonstrated principally by BIMeaser. This tool encourages the usage of dynamic simulation tools by reducing the amount of human labour necessary in the renovation project.

4.4.7 SOC 14 Integration of GIS data in BIM model for energy purpose

This KPIs want to assess how much linking BIM models with GIS can enhance the accuracy of building energy simulations. Within the BIMMS it is possible to visualize the BIM model of the building. In addition, the connection with GIS is available to improve the quality of building energy models.

4.4.8 SOC 15 Development of digital logbooks for renovated building; management of as-built data in operational BIM models

SOC 15 wants to assess the effectiveness of digital logbooks containing building-related data.

Digital Logbooks can be created in a specific section within the BIMMS. It includes all the information and data that can be collected and stored for a building. The digital logbook enables better management of the building information.

4.4.9 Results of assessment for Primary social KPIs

Questionnaires have been created and distributed to assess the social KPIs as outlined in D3.5. Especially, results of the questionnaires were grouped according to the different stakeholders. Figure 44-Figure 47 represent responses to the survey related to the primary KPIs given by Construction Companies – Facility Managers, Designers and Occupants.
As stated in Chapter 3.3 during the Italian workshop on January 19th a survey was spread and 30 replies were obtained.
Replies were filtered according to different stakeholders, dividing them in Construction companies – Facility Managers category or Designer category. People such as R&D project manager, Construction company members, Facility Manager (FM), Program Management Officer were assigned to the first category.
The feedback is in general quite good. The majority of respondents agree that BIM4EEB and its BIM-based toolkit can offer advantages such as improvement of building process management, time-saving, construction monitoring.

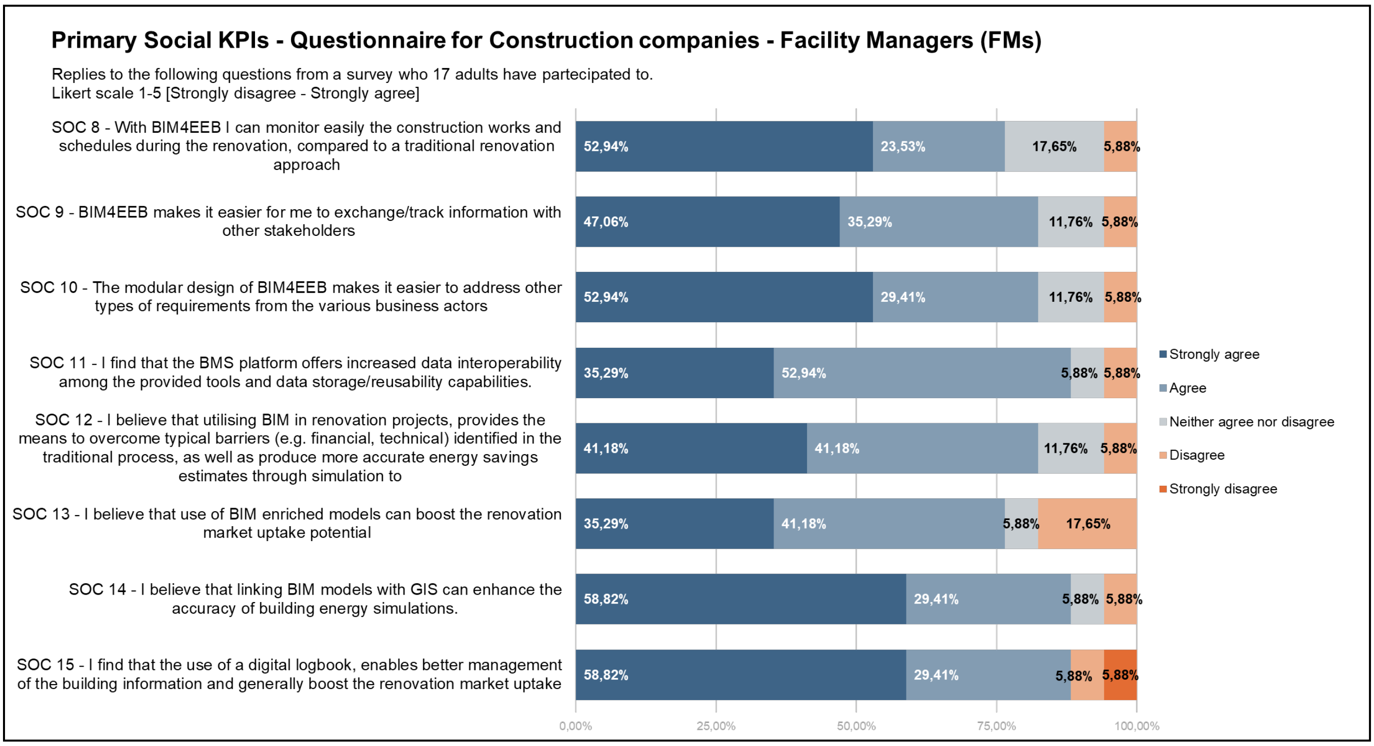


Figure 44 - Questionnaire replies to primary social KPIs by Construction companies – Facility Managers

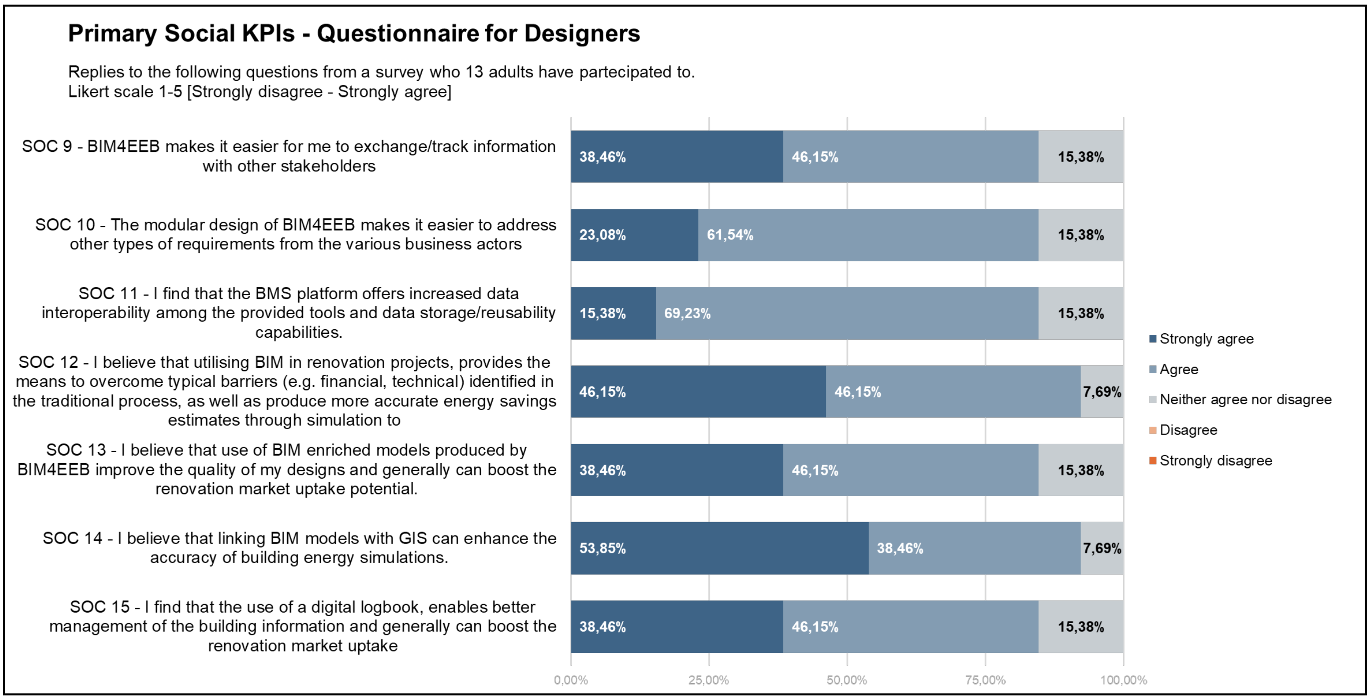


Figure 45 - Questionnaire replies to primary social KPIs by Designers

The survey among the inhabitants were spread in two different moments. The first one was carried out during a workshop with occupants on 21st November, the second instead refers to a 1 to 1 meeting on 23rd November with occupants that did not attend the workshop.

Totally, 9 inahbitants were involved and the results of the survey for the primary social KPIs is presented in the figure below (Figure 46).
During the demonstration, two elderly people, with low digital competencies although supported, had difficulties in using the tool and exploiting the functionalities. Therefore, another diagram, without these outliers was plotted in (Figure 47).

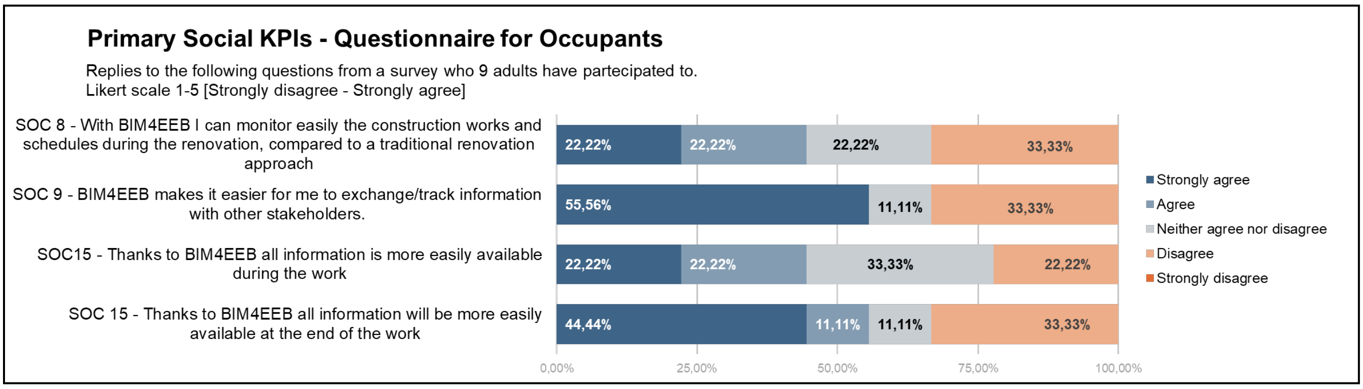


Figure 46 - Questionnaire replies to primary social KPIs by Occupants

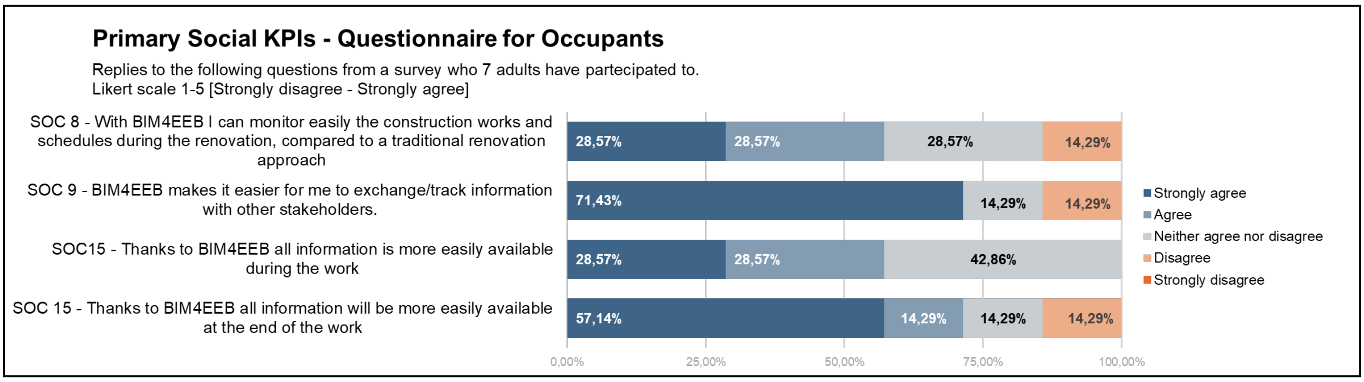


Figure 47 - Questionnaire replies to primary social KPIs by Occupants without outliers

5 Secondary KPIs

Starting from the KPI list (Annex II – List of the KPIs), the secondary KPIs are illustrated in the following chapters. In particular, some KPIs have been not taken into account. The list of indicators that were not defined in the end is the following:

- REP 5 Actual/planned conformance actions
  - Not relevant for the tools developed. There is no baseline to be used for comparison because these data are not generally measured and stored
- REP 6 Non-conformance issues during inspection reduction
  - Not relevant for the tools developed. There is no baseline to be used for comparison because these data are not generally measured and stored
- REP 7 Time reduction to fix quality issues
  - Not relevant for the tools developed. There is no baseline to be used for comparison because these data are not generally measured and stored
- ENV 2 Particulate Matter (PM) reduction
  - Although BIMcpd is able to analyse these data, there were no sensors able to monitor the indoor concentration. The sensor was unavailable due to COVID-19 related issues. Please check 2.3.2.
- ENV 3 Volatile Organic Compounds (VOC) reduction
  - Although BIMCPD is able to analyse these data, there were no sensors able to monitor the indoor concentration. The sensor was unavailable due to COVID-19 related issues. Please check 2.3.2.
- ENV 5 Safety issues/incidents/accidents (during inspection) reduction
  - Not relevant for the tools developed. There is no baseline to be used for comparison, because these data are not generally measured and stored.

5.1 Renovation process indicators

5.1.1 REP 3 Actual/planned conformance - time

5.1.1.1 Introduction:

The scope of this KPI is to demonstrate a better accuracy of the renovation process time compared to the baseline/traditional process, which will result as deviation percentage. Accuracy is calculated from deviation.

5.1.1.2 Assessment methodology and baseline calculation

Baseline and methodology are described in chapter 4.1.1.

5.1.1.3 Results:

The actual/planned conformance measured through the KPI is reported in the following table:

Table 28 Renovation process times accuracy

ID	Country	N. flats	Planned Renovation time	Actual Renovation time	Accuracy
VIA DELLA BIRONA	Monza	65	299 days	287* days	**96%**

*** without considering the delay due to pandemic situation and supply delay, the effective duration of 536 days has not to be decreased by the total extensions due to covid-19 related, i.e. of 236 days (see Table 13), thus (534-247) days = 287 days**

5.1.2 REP 4 Actual/Planned conformance - cost

5.1.2.1 Introduction:

The scope of this KPI is to demonstrate a better accuracy of the renovation process time compared to the baseline/traditional process.
Better accuracy of the renovation process **cost** considering the design phase, compared to the baseline/traditional process. which will result as deviation percentage. Accuracy is calculated from deviation.

5.1.2.2 Assessment methodology and baseline calculation

Baseline and methodology are described in chapter 4.1.1.

5.1.2.1 Results:

The actual/planned conformance measured through the KPI is reported in the following table

Table 29 Renovation process costs accuracy

ID	Country	N. flats	Planned Renovation time	Actual Renovation time	Accuracy
VIA DELLA BIRONA	Monza	65	€ 1.594.654,81	€ 1.146.008,74	72%

5.2 Comfort indicators

5.2.1 COM 1 Adaptive Predicted Mean Vote (PMV)

5.2.1.1 Introduction:

Adaptive PMV (based on PMV) predicts the mean value of the overall thermal sensation of a person as a function of environmental parameters: air temperature, mean radiant temperature, air velocity, and air humidity.

5.2.1.1 Assessment methodology and baseline calculation

PMV calculation requires the following main inputs: activity (metabolic rate), clothing insulation and the four environmental parameters such as air temperature, mean radiant temperature, air velocity, and air humidity.

BIMcpd uses a thermal comfort javascript library to calculate the PMV & PPD and is viewable in the Data Viewer section of the Performance Evaluation Tool. It is based on the CBE Thermal Comfort Tool developed by Berkeley University of California. The tool can be viewed here: https://comfort.cbe.berkeley.edu/ [CBE (Center for the Built Environment), 2022].
The calculation compiles with standard ISO 7730 [European Standard, 2006] and ASHRAE55-2021 [ASHRAE, 2021]. Not all the environmental parameters required by the standard can be retrieved by the sensors and in particular the air velocity and the mean radiant temperature values.
To overcome this limitation, some assumptions are made in the calculation. Each apartment is assumed as a "homogeneous not severe thermal environment", meaning that the difference between the mean radiant temperature and the air temperature is considered negligible. Another hypothesis assumes that the air velocity is equal to 0.1 m/s. Under these assumptions the operative temperature is calculated as an average between air temperature and mean radiant temperature, hence the latest values are equal to each other.

The default tool setup is the following:
Average Operative Temperature - t_{op} = 25°C
Average Relative Humidity = 50% measured value over the period
Air Speed - v_{air} = 0.1 m/s
Clothing Level = 0.61

- 0.5 clo – typical summer indoor clothing
- 1.0 clo – typical winter indoor clothing

MetabolicRate = 1 Met (as a person seated)

As can be seen in the tool user interface (Figure 48 Figure 49), the inputs of Average operative temperature, relative humidity, air speed, clothing level and Metabolic Rate can all be altered in calculating the BIMcpd thermal comfort calculations tool.

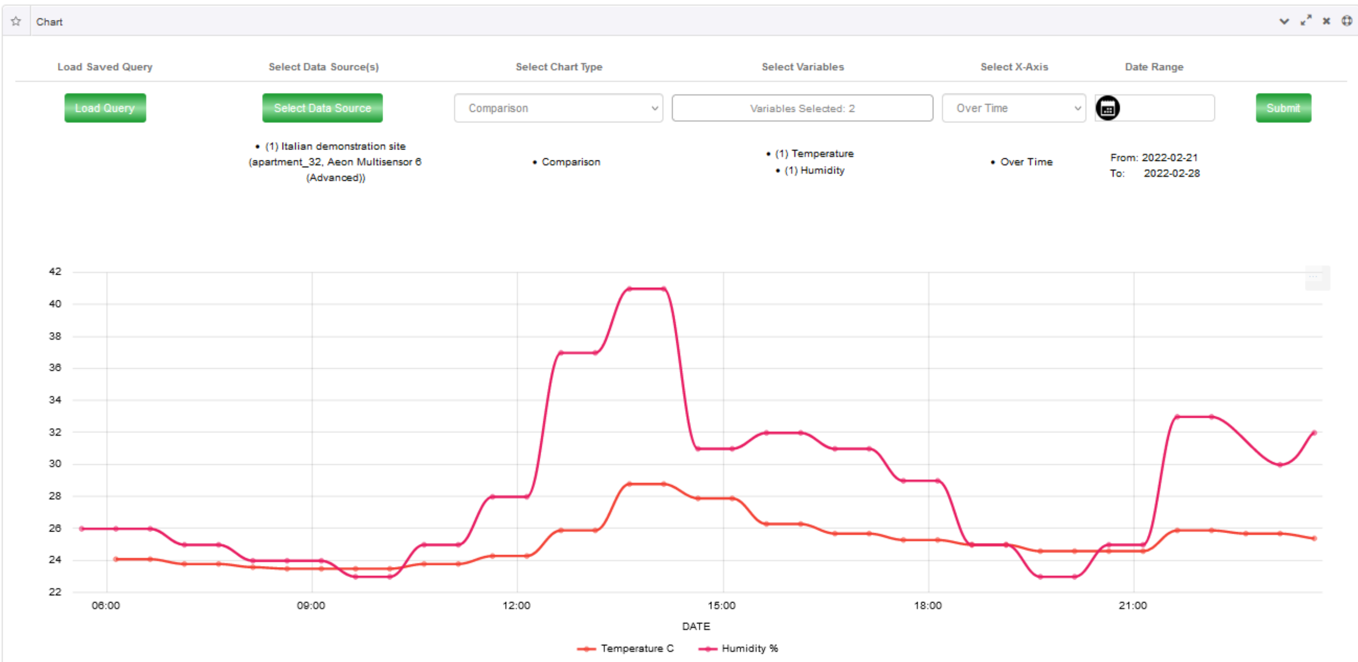


Figure 48 - Temperature & Humidity plotted for an apartment over a 1 week period – Data Viewer Section

If the input values are coloured orange, it means that the values have been calculated from the data submitted in the proceeding Data Viewer section. In case in Figure 48 the Data Source graphed included both Temperature and Humidity readings and the average of those reading was obtained and used in the Thermal Comfort Calculations.
Regarding the PMV and PPD readings if the values comply with the standard threshold for thermal neutrality then the values will be green otherwise they will be red.

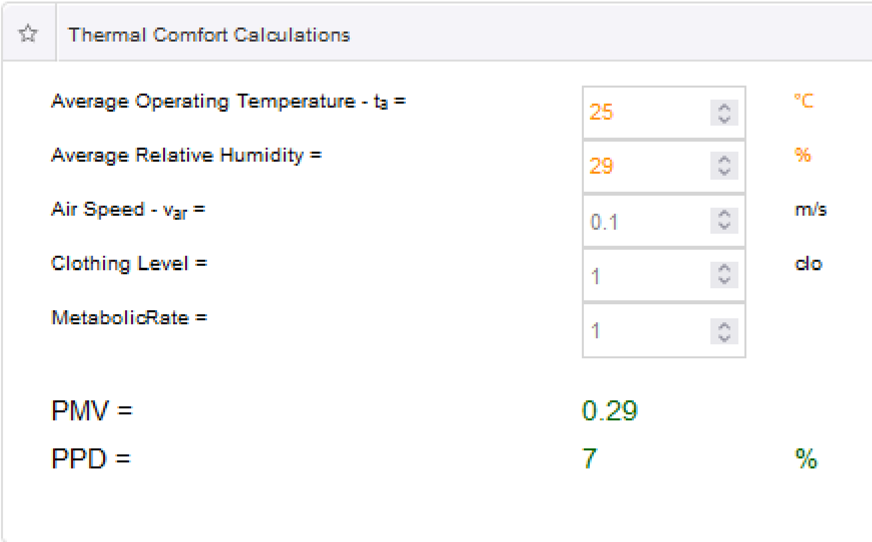


Figure 49 - PMV & PPD values calculated using average Temperature & Humidity readings – Tool interface

PMV is calculated on an hourly basis, therefore it is not advisable to provide a single value as a representative KPI for the project. For this reason, it was chosen to plot only a few average PMV values, evaluated for representative flats and to give an idea of the variability of the climatic conditions inside the monitored flats.

Assuming the equivalent sensor positions in the different flats, this variability depends mainly on the different settings of the indoor radiators, as well as the habits of the users, but also the exposure characteristics of the flats. A sample of five apartments was selected. Two apartments from the first floors of the building, two from the latest floors and one from the middle were selected. The Temperature & Humidity readings across a week were collected and then used to calculate the Thermal Comfort Values graphed and averaged. This was done for 3 months, representative of the beginning, development and almost end of the heating season: February 2021, December 2021 and October 2021. In each case, the last week of the month was selected. Summer months were excluded because of a need of a more relevant approach based on adaptive comfort. The results can be seen in Table 30 below.

5.2.1.2 Results

The results shown are examples of the internal conditions of the apartments in winter months. The standard PMV index scale ranges from –3 (cold) to +3 (hot), where the thermal neutrality is expressed with a vote -0.5< PMV < 0.5.

The results shown are examples of the internal conditions of the apartments in winter months.

On average the conditions inside the flats are considered to be within the optimal standard of comfort, with some mild variations towards slightly cold. It is interesting to note how negative and positive peaks of

PMV occur in limited portions of time during the day and in relation to localised phenomena such as: hypothetical opening of the windows for air change or switching off of the heating system. The greatest variability in temperature and comfort conditions is experienced on high floors and floors in contact with the ground.

Table 30 PMV values for 5 sample apartments

Apt.	Floor	Multis Sensor	Date From	Date To	Average Temp. (°C)	Average Hum. (%)	Average PMV	Max PMV	Min PMV
A	0	B	21/02/22	28/02/22	24.5	20	**0.09**	0.7	-0.39
A	0	B	24/12/21	31/12/21	23	32	**-0.21**	0.01	-0.63
A	0	B	24/10/21	31/10/21	22.5	42	**-0.27**	1.25	-1.28
B	0	B	21/02/22	28/02/22	23	30	**-0.22**	0.15	-0.51
B	0	B	24/12/21	31/12/21	21	39	**-0.69**	-0.02	-1.23
B	0	B	24/10/21	31/10/21	22	47	**-0.37**	0.27	-1.03
F	3	B	21/02/22	28/02/22	25.5	23	**0.38**	0.57	0
F	3	B	24/12/21	31/12/21	23.5	34	**-0.06**	0.33	-0.51
F	3	B	24/10/21	31/10/21	21.5	43	**-0.53**	0.3	-1.17
H	6	A	21/02/22	28/02/22	25.5	23	**0.38**	0.84	-1.07
H	6	A	24/12/21	31/12/21	24.5	36	**0.22**	0.65	-0.69
H	6	A	24/10/21	31/10/21	24	43	**0.14**	0.84	-0.93
I	7	A	21/02/22	28/02/22	25	29	**0.18**	0.59	-1.15
I	7	A	24/12/21	31/12/21	25	39	**0.38**	0.21	-0.44
I	7	A	24/10/21	31/10/21	26.5	43	**0.01**	0.56	-0.83

5.2.2 COM 2 Predicted Percentage of dissatisfaction (PPD)

5.2.2.1 Introduction

The PPD quantifies the percentage of the people who felt more than slightly warm or slightly cold.

The quantification of PPD values has been done by taking a sample of five apartments across the demo site and taking the Average, Max and Min PPD values across a week of values. The results can be viewed in this section.

5.2.2.1 Assessment methodology and baseline calculation

As stated in the Introduction of this chapter and in the reference standard [ISO International Standard, 2006] PPD is a variable derived directly from PMV and the methodology for the calculation was already presented in the methodology section in 5.2.1.1.

5.2.2.2 Results:

The results shown are examples of the dissatisfaction of the users of the apartments in winter months. As stated before PMV and PPD are directly linked. The thermal expressed with a vote -0.5< PMV < 0.5 ranges the maximum percentage of dissatisfied to 10%. Also in this case the on average conditions experienced by the inhabitants are considered satisfactory in terms of comfort and after the renovation.

Table 31 PPD values for 5 sample apartments

Apt.	Floor	Multis Sensor	Date From	Date To	Average Temp. (°C)	Average Hum. (%)	Average PPD	Max PPD	Min PPD
A	0	B	21/02/22	28/02/22	24.5	20	5	15	8
A	0	B	24/12/21	31/12/21	23	32	6	5	13
A	0	B	24/10/21	31/10/21	22.5	42	7	38	39
B	0	B	21/02/22	28/02/22	23	30	6	5	11
B	0	B	24/12/21	31/12/21	21	39	15	5	37
B	0	B	24/10/21	31/10/21	22	47	8	6	27
F	3	B	21/02/22	28/02/22	25.5	23	8	12	5
F	3	B	24/12/21	31/12/21	23.5	34	5	7	10
F	3	B	24/10/21	31/10/21	21.5	43	11	7	34
H	6	A	21/02/22	28/02/22	25.5	23	8	20	29
H	6	A	24/12/21	31/12/21	24.5	36	6	14	15
H	6	A	24/10/21	31/10/21	24	43	5	20	23
I	7	A	21/02/22	28/02/22	25	29	6	12	33
I	7	A	24/12/21	31/12/21	25	39	8	6	9
I	7	A	24/10/21	31/10/21	26.5	43	5	11	20

5.2.3 COM 3 and COM 5 Thermal discomfort factor and Visual Discomfort Factor

5.2.3.1 Introduction:

The scope of this KPI is to enable the extraction of the thermal discomfort factor as an index of probability (0-1) to indicate the level of personalized comfort under different environmental conditions. More details about KPI/metric calculation are presented in D 6.7 defined in D3.5 and reported in D 8.1

Due to the similarity of the approaches for evaluating both thermal and visual discomfort factors, the two are grouped and presented in the same chapter.

5.2.3.2 Assessment methodology and baseline calculation

The calculation methodology was presented in details as part of the work in D6.7 (using MLbased data-driven techniques). Then by taking into account the probability level of comfort/discomfort indicative temperature boundaries of preference/non preference are extracted. The scope of the BIM4Occupants tool is to act as an informative tool for the building occupants on the way to get engaged in building performance-related activities. In terms of thermal comfort, the users have been asked to provide information about their initial thermal and visual comfort boundaries. Then, taking into account actual environmental conditions (as logged by the sensors installed in premises) as well as the users' interaction (comfort settings via the app), fine grained thermal and visual comfort profiles are defined.

An indicative estimation of the thermal comfort cure for apartment_H is presented below.

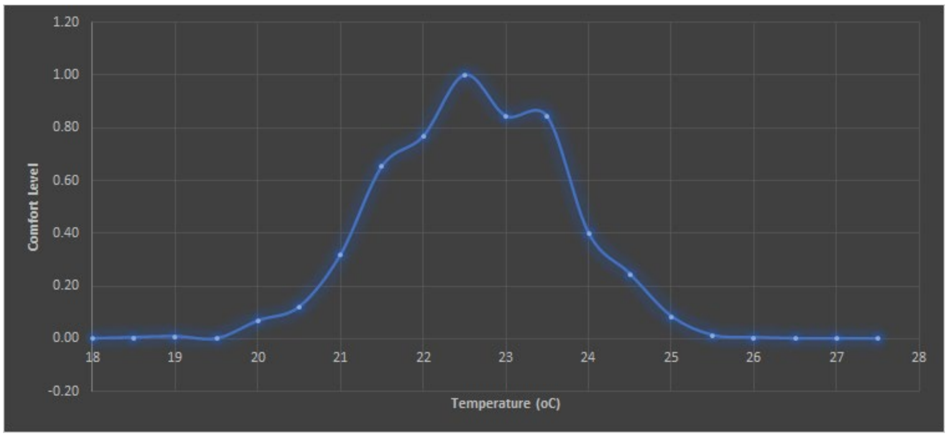


Figure 50 - Thermal Comfort Curve for apartment_H

The percentage value represents the quantification of the level of comfort a user feels under specific conditions (100% max comfort, 0 % max discomfort). Then, post processing of this curve applies to extract the values of max comfort as well as comfort boundaries (based on the statistics analysis performed over the data)

5.2.3.3 Results

In the following table, the results for both KPIs (COM3 and COM5) are presented.

The results presented are the most representative ones which, thanks to the greater number of answers provided by users through the dedicated section in BIM4Occupants, allowed us to provide more accurate statistics.

Table 32 Thermal and Visual discomfort indicator

Apartment	Indicator	Max Comfort	Comfort Boundary
apartment_L	Thermal (°C)	24	20.5
	Visual (lux)	160	90
apartment_A	Thermal (°C)	23	20
	Visual (lux)	140	80
apartment_I	Thermal (°C)	22	19.5
	Visual (lux)	160	90
apartment_G	Thermal (°C)	23	20.5
	Visual (lux)	270	140
apartment_H	Thermal (°C)	22.5	20.5
	Visual (lux)	270	140
apartment_E	Thermal (°C)	22	19.5
	Visual (lux)	190	100

Note: For thermal comfort boundary we present only the low boundary level, considering that the demonstration was performed during the winter period (and thus feedback about non comfort conditions was provided for low temperature conditions).

5.2.4 COM 4 Operative Illuminance

5.2.4.1 Introduction

The value assessed is not a KPI, rather a statistical representation of the illuminance level in the building environment. The calculation formula as defined in D3.5 is then reported in D 8.1. The values are measured in Lux and rely on the data gathered through the Multisensor B installed in each apartment. The KPI assesses the people's satisfaction in terms of illuminance compared to a reference value.

5.2.4.2 Assessment methodology and baseline calculation

The overall idea is to calculate the illuminance level over a time period and compare it with a reference value (discomfort boundary - see COM 5). The most important part of the work is the definition of reference time periods for the evaluation addressing seasonality (e.g., the impact of daylight during summer and winter period) and time-related (daylight vs artificial lighting) parameters. In the analysis we have considered only events at presence hours for a 5-month period (October 2021 – February 2022).

5.2.4.3 Results

Exemplification results of selected apartments are reported, to demonstrate the data deviation related to the different ages and the different number of occupants in the apartments. In the following table, the aggregate statistics over the luminance are presented. Data for apartment L consider a two-month period (Jan 2022- Feb 2022), because it was not originally intended as part of the project and was added after the positive outcome of the engagement activities done.

Table 33 Average illuminance in selected apartments

Apartment	Avg. Illuminance (lux)
apartment_L	140
apartment_A	110
apartment_I	130
apartment_G	220
apartment_H	220
apartment_E	160

5.2.5 COM 6 Average Noise Level

5.2.5.1 Introduction

The value assessed is not a KPI, rather a statistical representation of the noise level in the building environment. The calculation formula as defined in D3.5 is then reported in D 8.1. The values are measured in dB and the values rely on the data gathered through the Multisensor A installed in each apartment. The KPI assesses the level of noise in the building environment compared to reference values.

5.2.5.2 Assessment methodology and baseline calculation

The overall idea is to calculate the noise level over a time period and compare it with a reference value. The analysis was performed for the demonstration period of the project and the reference values (aggregate statistics over the period of time as well as % of values above threshold) are presented in the following table (for CO_2 and Noise statistics) – metering data over a 5 month period (October 2021 – February 2022) (when data available).

Threshold values for noise are defined in the literature analysis performed in D2.5 [BIM4EEB, 2019a]. More specifically, the threshold for noise in residential apartments is 70 dB.

5.2.5.3 Results

In the following table, the aggregate statistics for the noise values are presented and compared, considering sample apartments among the ones monitored. Data for apartment L considered a two month period (Jan 2022- Feb 2022), because it was not originally intended as part of the project and it was added further because of the engagement activities carried out. The results report the average value over the period, such as the percentage of values over the identified threshold.

Table 34 Average noise in selected apartments

Apartment	Average Noise (dB)	% Above threshold
apartment_L	37.7	2.58 %
apartment_A	47.5	3.87 %
apartment_I	55.5	8.28 %
apartment_G	52.1	6.96 %
apartment_H	48.2	3.65 %
apartment_E	34.4	2.81 %

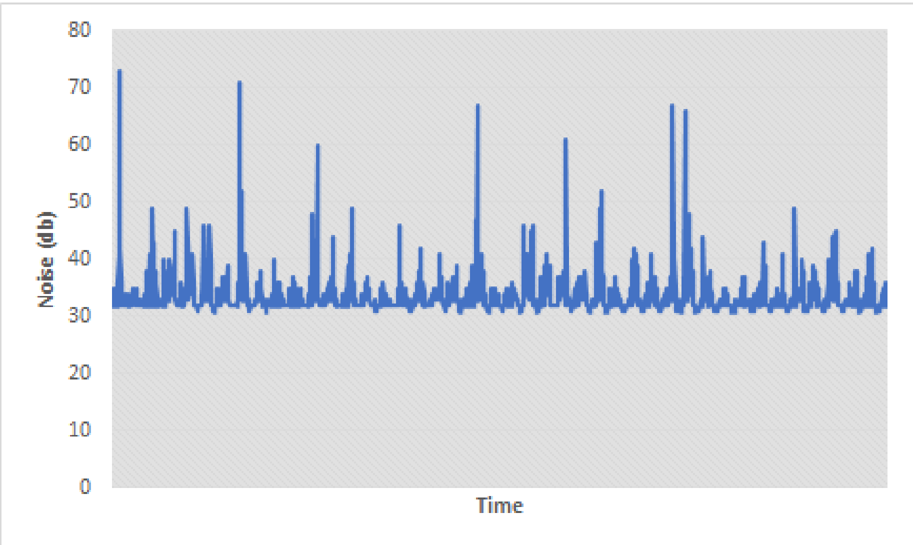


Figure 51 - Indoor Noise condition for a sample apartment

5.3 Economic indicators

5.3.1 ECON 1 Annual Cost Savings

5.3.1.1 Introduction

This KPI evaluate the reduction in the building operational costs after the renovation

5.3.1.2 Assessment methodology and baseline calculation

The cost of heating and electricity for the building's shared services (i.e. lighting, elevators, water pumps) are considered for the assessment of the operational costs baseline. Additional annual maintenance fees for heat generator inspection and cleaning services are also considered. The data are reported in Table 35 and Table 36.

The latest three heating seasons are compared to evaluate an average annual heating cost.

Table 35 Annual costs for electricity and standard maintenance in Via della Birona Building

Annual average Electricity costs	9’500 € (VAT Included)
Annual maintenance cost of the heat generator	1’500 €(VAT Included)
Annual cleaning service costs	5’500 €(VAT Included)

Table 36 Measured gas costs for heating - Via della Birona Building. The cost for the season 2021-22 is estimated in accordance with the forecasted energy savings due to renovation, such as the estimated increased cost of natural gas for the year 2022.

Heating Season	Annual costs for heating (VAT Excluded)	Annual costs for heating (VAT Included)
2019-2020	33'758.21 €	41'185.02 € (Vat 22%)
2020-2021	30'691.45 €	37'443.58 € (Vat 22%)
2021-2022	47'118.44 €*	49'474.36 € (Vat 5%)

The estimated data of the latest season are excluded, due to a relevant increase in the Natural gas price and rely on a more conservative estimate of the possible savings. The gas price per m^3 in 2022 doubled with respect to the years 2019, 2020 and 2021. The availability of an updated price just for January 2022 does not allow us to provide enough accurate estimates for future prices.

Assuming an average of **32’221€ for heating**, the annual operational cost baseline for via della Birona Building is **48’721 €.**

5.3.1.3 Results

After the renovation, a 38% energy saving for heating can be assumed in accordance with Chapter 4.3 and 5.4. A reduction of **12’244 €** of the annual operational cost determines as a **35% saving.**

5.3.2 ECON 2 Net Present Value (NPV)

5.3.2.1 Introduction

This KPI assesses the NPV considering nominal costs and discount rate based on the projected actual future costs to be paid, including general inflation and deflation.

5.3.2.2 Assessment methodology and baseline calculation

The building in Via della Birona is publicly owned and is an example of social housing with subsidized rents. This implies that ALER, as a public body, cannot be considered a real estate operator which can use the NPV as a measure of investment profitability:

- The building, being public property, cannot normally be alienated. Hence, the increase in the value of the property resulting from the retrofit activities could not be directly exploited.
- The rent fees, after the renovation, can be increased only up to 0.14%, by regional rules.
- The operational running costs are shared between the occupants and this amount is already included in the rent.

For the purposes of the analysis, congruent assumptions are made consistently with a privately owned building scenario. The calculation will follow these hypotheses:

- Discount rate: equal to 3.3% - average value for Societal EU members (5.7% for privates) [Hermelink, 2015; European Commission, 2022],
- Reference period:25 years,
- Energy savings as stated in ECON1 chapter 5.3.1. The assumed yearly price escalation for natural gas is 4%;
- Gross floor area of the building: 5079 m^2,
- Estimated rent fee increase due to renovation: 1.4 €/m^2 [Agenzia Entrate, 2022],
- Estimated property value increase due to renovation: 400 €/m^2 [Agenzia Entrate, 2022].

Table 37 Yearly NPV calculation over a reference period of 25 years.

Year	Renovation	Energy savings	Rent Increase	Sum	Annual NPV
2020	-274'467.07 €		- €	-274'467.07 €	-274'467.07 €
2021	-663'615.32 €		- €	-663'615.32 €	-642'415.60 €
2022	-207'926.35 €	12'244.00 €	68'827.20 €	-126'855.15 €	-118'879.64 €
2023	- €	12'733.76 €	85'327.20 €	98'060.96 €	88'960.08 €
2024	- €	13'243.11 €	85'327.20 €	98'570.31 €	86'565.50 €
2025	- €	13'772.83 €	85'327.20 €	99'100.03 €	84'250.44 €
2026	- €	14'323.75 €	85'327.20 €	99'650.95 €	82'012.40 €
2027	- €	14'896.70 €	85'327.20 €	100'223.90 €	79'848.92 €
2028	- €	15'492.57 €	85'327.20 €	100'819.77 €	77'757.65 €
2029	- €	16'112.27 €	85'327.20 €	101'439.47 €	75'736.30 €
2030	- €	16'756.76 €	85'327.20 €	102'083.96 €	73'782.66 €
2031	- €	17'427.03 €	85'327.20 €	102'754.23 €	71'894.58 €
2032	- €	18'124.11 €	85'327.20 €	103'451.31 €	70'070.00 €
2033	- €	18'849.08 €	85'327.20 €	104'176.28 €	68'306.91 €
2034	- €	19'603.04 €	85'327.20 €	104'930.24 €	66'603.36 €
2035	- €	20'387.16 €	85'327.20 €	105'714.36 €	64'957.48 €
2036	- €	21'202.65 €	85'327.20 €	106'529.85 €	63'367.44 €
2037	- €	22'050.75 €	85'327.20 €	107'377.95 €	61'831.48 €
2038	- €	22'932.78 €	85'327.20 €	108'259.98 €	60'347.90 €
2039	- €	23'850.09 €	85'327.20 €	109'177.29 €	58'915.05 €
2040	- €	24'804.10 €	85'327.20 €	110'131.30 €	57'531.32 €
2041	- €	25'796.26 €	85'327.20 €	111'123.46 €	56'195.17 €
2042	- €	26'828.11 €	85'327.20 €	112'155.31 €	54'905.11 €
2043	- €	27'901.24 €	85'327.20 €	113'228.44 €	53'659.68 €
2044	- €	29'017.29 €	85'327.20 €	114'344.49 €	52'457.49 €
2045	- €	30'177.98 €	85'327.20 €	115'505.18 €	51'297.17 €
2046	- €	31'385.10 €	85'327.20 €	116'712.30 €	50'177.41 €
2047	- €	32'640.50 €	85'327.20 €	117'967.70 €	49'096.94 €

5.3.2.3 Results

An NPV of 624’766.14 € is reached after 25 years. This conservative estimate does not include the increment in the property value of 2'300'000.00 €. If only the energy savings are included, neglecting the revenues for the increased renting fee, the NPV doesn’t reach a positive value during the project lifespan.

This result is "distorted" by the impossibility of raising rents, but considering that the building is intended for the poorest sections of the population, for whom bills have a much greater impact than rent, the reduction in management costs, both from the point of view of the owner and the tenants, has a very positive social impact.

5.3.3 ECON 3 Pay-back Period

5.3.3.1 Introduction

The aim of the KPI is to compute Pay-back as the period, in years, required to recover the funds spent in an investment, in other words the time required for an investment to reach a breakeven point.

5.3.3.2 Assessment methodology and baseline calculation

The evaluation is done under the same premises highlighted in chapter 5.3.2 considering the cumulative algebraic sum of the revenues, savings (positive values) and costs for renovation (negative values).

5.3.3.3 Results

The Payback period for the investment is reached in **16 years.**

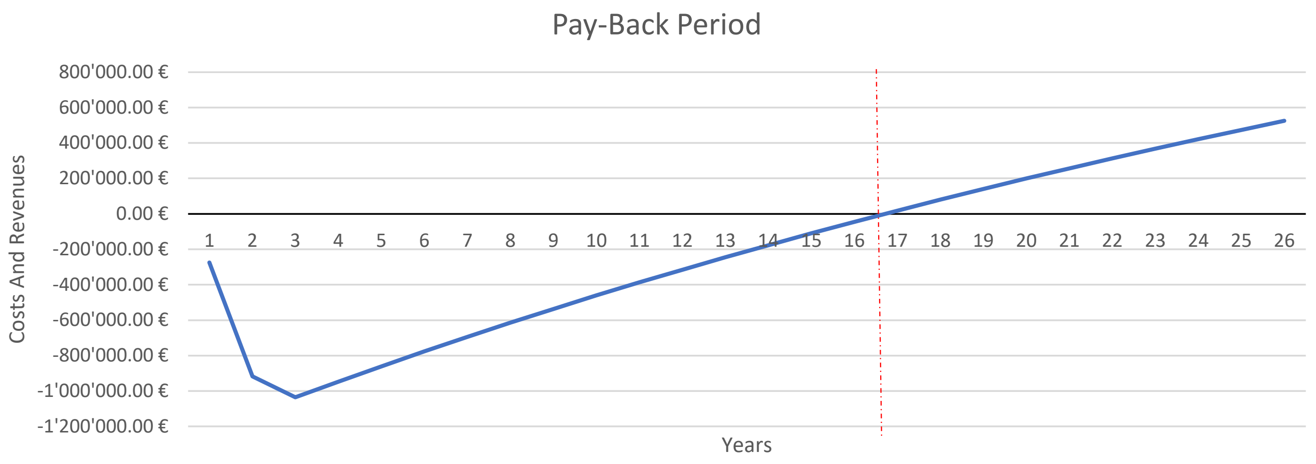


Figure 52 - Pay Back period graph

5.3.4 ECON 4 ROI - Return on Investment

5.3.4.1 Introduction

The KPI assess the energy measures for the whole building by using the overall investment costs and the saving in running costs for energy.

5.3.4.2 Assessment methodology and baseline calculation

The evaluation is done under the same premises highlighted in chapter 5.4.2 considering the cumulative algebraic sum of the revenues and savings (positive values) and investment costs for renovation (negative values). Future natural gas and electricity price trends are not included, considering that the total investment costs for renovation used for the comparison are not actualized.

- Sum of the revenue for rents (25 years): 2'202'000.00 €
- Sum of the energy savings: - 298'481.12 €
- Total investment costs for renovation: 1'146'008.74 €

5.3.4.3 Results

The ROI in 25 years will be 120% considering all the revenues and savings. The ROI will be negative if only the energy savings are included in the calculation.

Again, the results appear less interesting than they really are, because a reduction in bills, for the tenants of public housing, often affected by fuel poverty, translates into a greater possibility of paying rents and, consequently, in a positive effect for both the tenants and the owner.

5.3.5 ECON 5 Life Cycle Cost (LCC)

5.3.5.1 Introduction:

LCC defines the business framework for renovation activities, by comparing the investment costs with the economic savings achieved due to the energy conservation measures introduced during the renovation. LCC analyzes and considers all cash inflows and outflows over the useful life of the project, reducing each flow to its present value.

5.3.5.2 Assessment methodology and baseline calculation

The baseline for the calculation includes cash inflows and outflows as highlighted in Chapter 5.3.1 and Chapter 5.3.2. The hypotheses for the NPV calculation are the same. No LCA related factors are considered, nor are costs for major repairs and modernisations during the standard 25 years lifecycle after the renovation. Renovation costs are used instead of acquisition ones Table 38 provide a summary of the values considered.

Table 38 Estimated costs used in the LCC calculation.

Type	Amount
Renovation costs	1'146'008.74 €
Yearly maintenance costs (services and cleaning)	7000 € (estimate)
Yearly electricity costs	9500 €
Yearly natural gas costs for heating	32221 €

5.3.5.3 Results

Assuming a discount of 3.3% as stated in ECON 2 (Chapter 5.3.2), the **LCC for the project is 2'025'064.69 €.** Future natural gas and electricity price trends are not included.

5.4 Energy performance indicators

5.4.1 ENE 1 Energy Savings

Calculating the percentage difference between measured and baseline consumption data within a predefined period

Baseline: The baseline measured gas consumption for a heating season is defined in chapter 4.3.1.2. The **Oct 2019-Jan 2020** season was selected to present the baseline so its months correspond to the measurement period. The value for **ER_E is 467,040 kWh**.

How to define the improved value: The corresponding gas consumption is taken from the measurement period **Oct 2021- Jan 2022** after renovation. The measurement period was not a full year. The value for **ES_C is 289,497 kWh**.

Calculating the equation the **ENE 1 Energy savings ES = 38%**

5.4.2 ENE 2 Energy Savings (per building component)

Calculating the percentage difference between measured and baseline consumption data within a predefined period for different building components (e.g. HVAC, lights etc…)

Baseline: The simulated gas consumption was selected as a baseline. The new outside walls and windows were applied during one heating season and the impact of each measure cannot be separated from each other, so measured gas consumption cannot be used. The value for **ER_E is 742,376 kWh/a**.

Results: Both measures (wall and window renovation) were applied to the baseline simulation model and calculated the result one by one. The values for the **ER_C** were:

- gas consumption after outside wall renovation **ES_C is 646 061 kWh/a**
- gas consumption after window renovation **ES_C is 559,785 kWh/a**

Calculating the equation for each corresponding measure gives:

- ENE 2 Energy Savings (outside wall renovation) **$ES_{es,wall}$ = 13%**
- ENE 2 Energy Savings (window renovation) **$ES_{es,window}$ = 25%**

5.4.3 ENE 5 Total Use of Primary Energy (TUPE)

5.4.3.1 Introduction

The purpose of this KPI is to evaluate the use of primary energy expressed as the indicator of Cumulative Energy Demand during the lifecycle of the project.

5.4.3.2 Assessment methodology and baseline calculation

Only operational energy was considered for the analysis. Additional inputs should have required a complete LCA analysis that was out of the scope of the project and not included in any of the tools developed. A 25 year reference lifecycle is then used.
The fuel sources measured in the following analysis are the gas for winter heating and the electricity for the building's shared services (lighting, elevators, water pumps).

The baseline consumption for natural gas refers to the measured consumption of the building during the winter season 2019-2020, reduced in accordance with the foreseen 38% energy saving. All the values are collected through energy bills. The renovated scenario assumes a 38% energy saving for the heating service in accordance with chapter 5.4.1. No electric energy saving is considered in the renovated scenario.
The primary energy factors (PEF) are 1.05 for Gas and 1.95 for electricity, considering for the latter only the non-renewable part. The data are in accordance with Annex 1 Italian Interministerial Decree of 26 June 2015 - Application of energy performance calculation methodologies and definition of prescriptions and minimum requirements for buildings [Ministro dello sviluppo economico, 2015].

Table 39 Total use of primary energy over a standardized lifecycle of 25 years – Renovated scenario

Fuel source	Estimated consumption (kWh)	PEF (-)	TUPE Primary energy (Year) (kWh)	TUPE Primary energy (25 Years) (MWh)
Natural Gas	457,325	1.05	480,195	12,004
Electricity	35,790	1.95	69,790	1,744

5.4.3.3 Results

The total use of operational primary energy for the **renovated scenario is 13,748 MWh** over a period of 25 years and for the selected building services. For the same services and considering the baseline scenario, without energy savings, the total use could have been **21,106 MWh**.

5.5 Social indicators

5.5.1 SOC 1 Ease of use for end users of the solution

SOC 1 aims at investigating the easiness of the solution.

End-users such as FM/Construction companies, Occupants and Designers can use the developed toolkit according to the different purposes.

For example, BIM4Occupants looks like a user-friendly application, intuitive and easy it its usage by inhabitants.

5.5.2 SOC 2 Beneficial for end-users

This KPI assesses the degree of advantages such as cost and time savings in the renovation interventions.

Each developed tool offers benefits from a different point of view. For example, the Fast Mapping toolkit allows to detect hidden elements within the wall and hence speeds up the scan to BIM process. BIM4Occupants enables inhabitants to monitor data related to their apartments and renovation interventions. BIMMS acts as the common data environment and it allows to connect the toolkit. BIMPlanner offers updated information about the plans and site progress operations with all stakeholders of a renovation project.

5.5.3 SOC 3 Occupants active involvement in the renovation phase

SOC 3 refers to the involvement of inhabitants and consequently, it is demonstrated by BIM4Occupants tool. The tool has been used to support inhabitants in the renovation activities monitoring and with the negotiation function, they have been involved also in planning the activities at the site (3.2.4.2).

5.5.4 SOC 4 Productivity improvement

SOC 4 aims at assessing how much Construction Companies/FMs and Designer can improve their productivity during the various stages of the renovation with BIM4EEB.

For example, BIMeaser can support decision-making in the early design stage of the renovation process. Stakeholders can provide the best solutions for clients thanks to the assessment of energy refurbishment design options offered by the tool.

Thanks to BIMPlanner the information about the plans and site progress operations are always updated, then better management of the on-site activities is possible.

5.5.5 SOC 5 Improvement in collaboration among teams

SOC 5 wants to assess how much BIM4EEB project supports collaboration within the work environment and helps to exchange information.

BIMMS and BIM4Occupants are two examples of tools that improve the collaboration between the involved actors offering, from one side, a platform to collect and share information and on the other side to give to inhabitants the possibility for collaborative planning and monitoring activities.

5.5.6 SOC 6 Improvement in safety at construction site

This KPI aims at investigating how much BIM4EEB makes FM/Construction companies and Occupants safer around the construction site.

BIMMS and BIMplanner can assist residents and other stakeholders by keeping them informed about site developments and health and safety advice.

5.5.7 SOC 7 Level of intuitiveness in user applications

SOC 7 estimates how FM/Construction Companies, Designers, and Occupants find the design of the toolkit intuitive and easy to use.

Among the developed tools, BIM4Occupants - studied for owners and inhabitants- offers an easy user interface that can be used without deep digital knowledge.

In the same way, BIMPlanner and BIMMS offer several complex instruments with a very user-friendly design.

5.5.8 Results of assessment for Secondary social KPIs

Questionnaires have been created and distributed to assess the social KPIs as outlined in D3.5. Especially, results of the questionnaires were grouped according to the different stakeholders. Figure 53-Figure 56 represents responses to the survey related to the secondary KPIs given by Construction Companies – Facility Managers, Designers and Occupants.

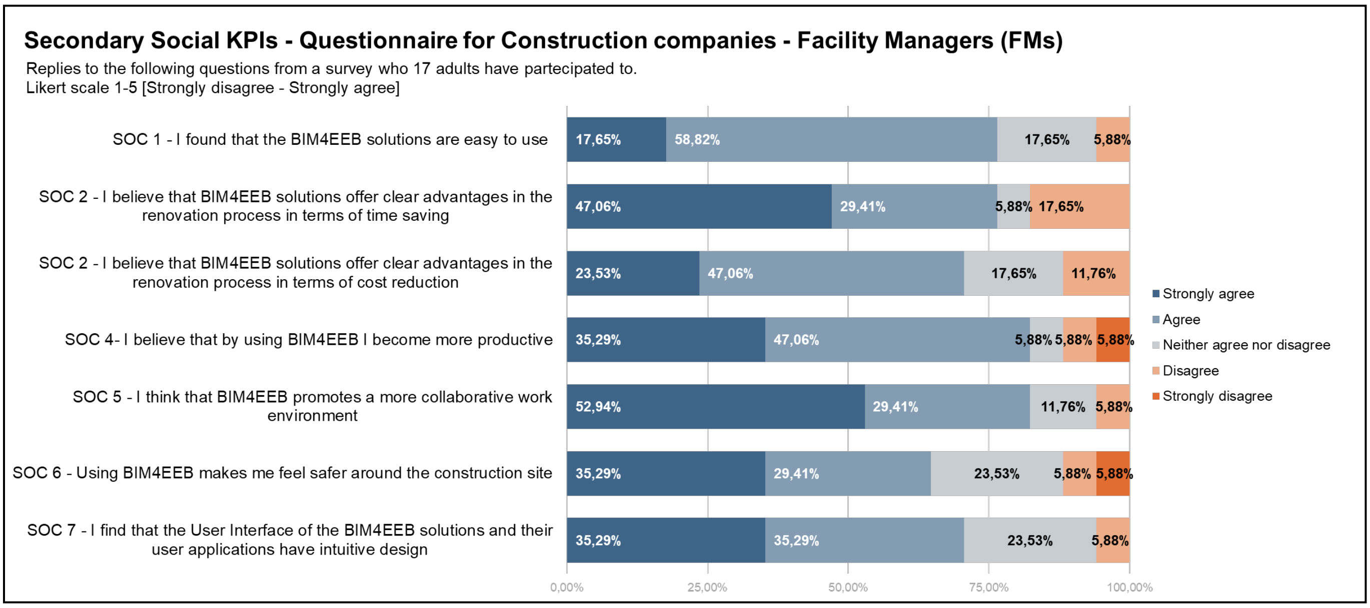


Figure 53 - Questionnaire replies to secondary social KPIs by Construction companies – Facility Managers

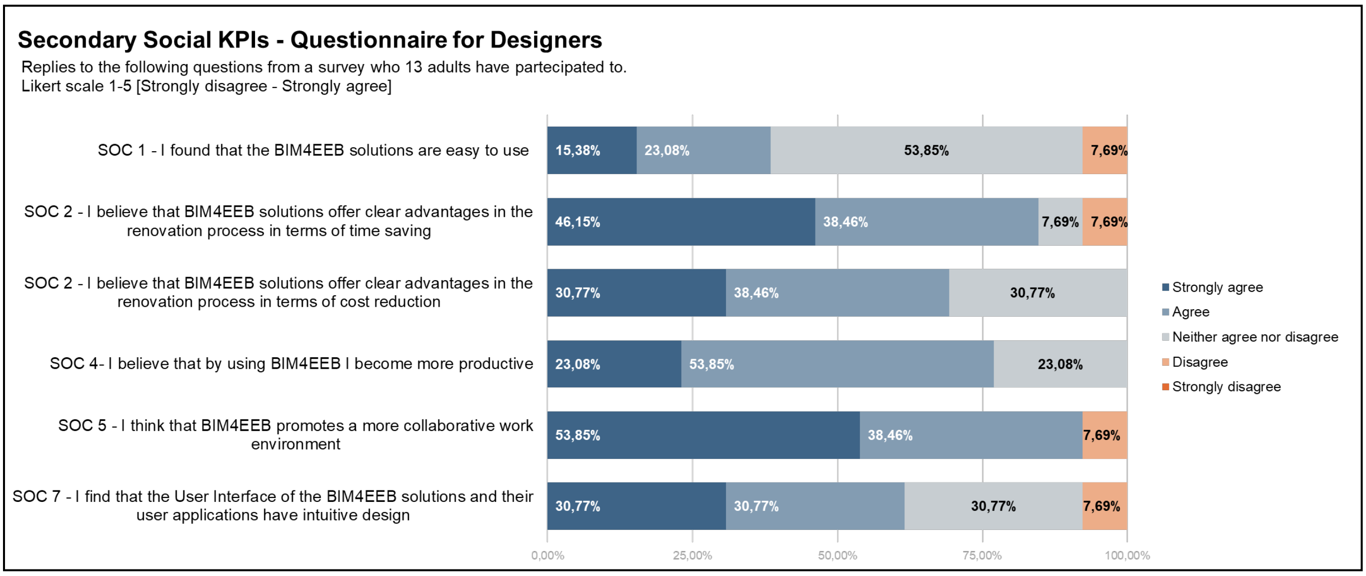


Figure 54 - Questionnaire replies to secondary social KPIs by Designers

9 inhabitants were involved in the survey and the results for the secondary social KPIs are presented in the figure below (Figure 55).
During the demonstration, two elderly people, with low digital competencies although supported, had difficulties in using the tool and exploiting the functionalities. Therefore, another diagram, without these outliers was plotted in (Figure 56).

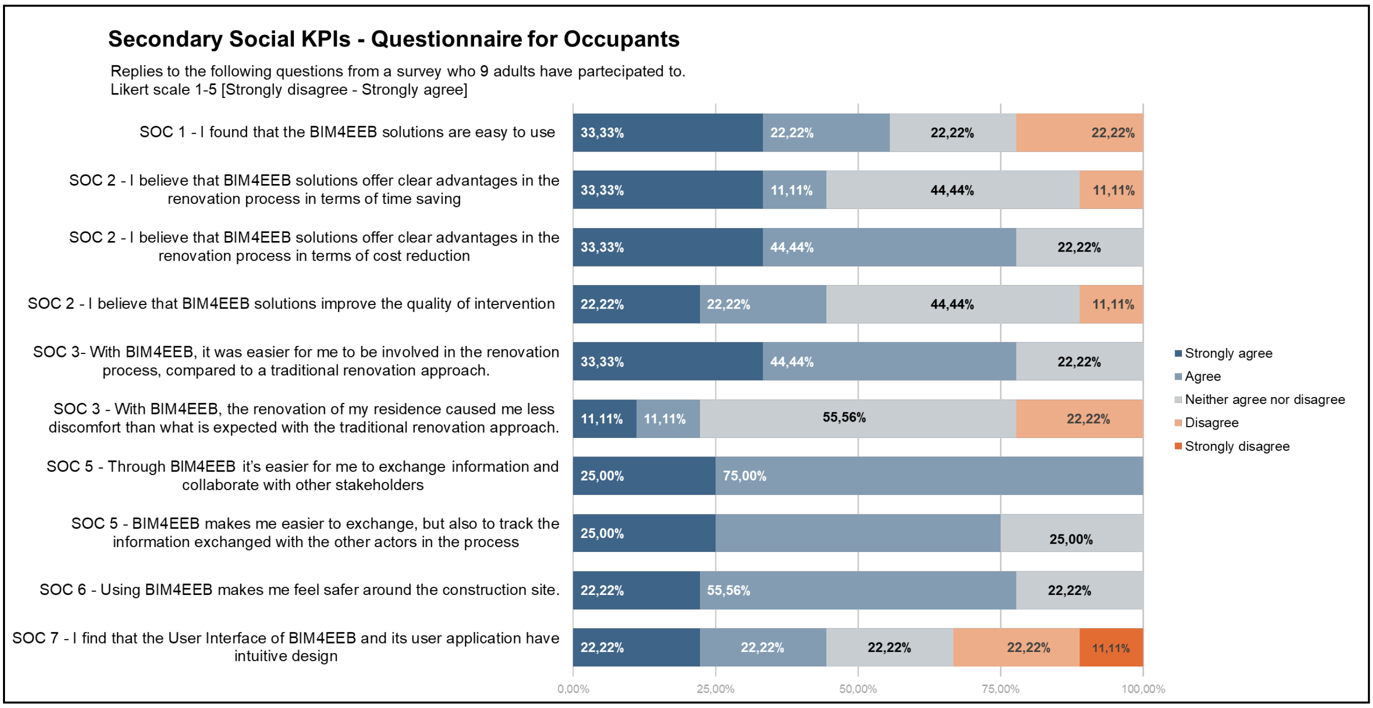


Figure 55 - Questionnaire replies to secondary social KPIs by Occupants

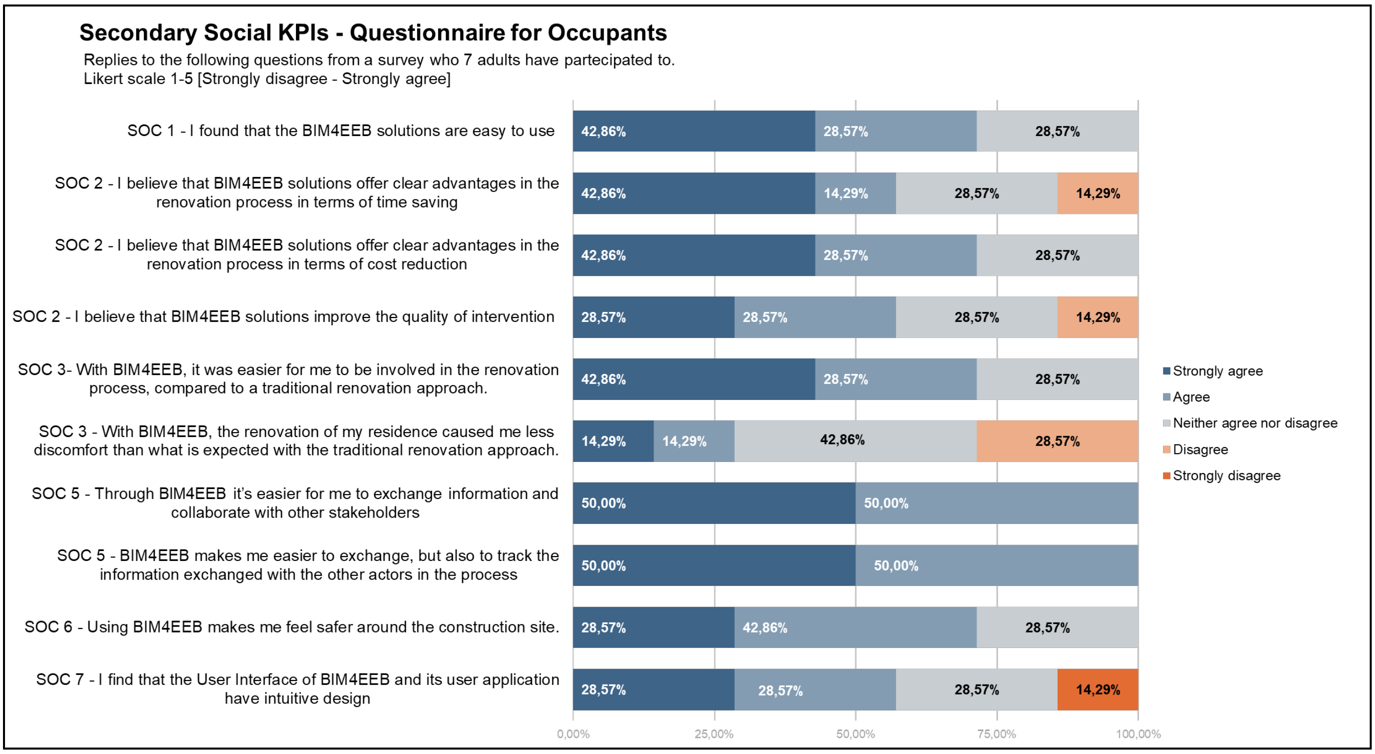


Figure 56 - Questionnaire replies to secondary social KPIs by Occupants without outliers

5.6 Environmental indicators

5.6.1 ENV 1 CO_2/CO compounds reduction

5.6.1.1 Introduction:

This KPI aims to assess the level of pollutant emissions (CO_2 in the project) compared to a reference value. The long-term IAQ evaluation vector of CO_2 concentrations KPI for a monitored space i and for a time-period T is performed by evaluating the specific average value over the time.

5.6.1.2 Assessment methodology and baseline calculation

The reference value for CO_2 compounds is defined in building standards and as stated in D3.5. Threshold values for IAQ were defined in the literature analysis performed in D2.5 and 1000 ppm CO_2 was assumed as a reference value for indoor air quality assessment in a standard environment. Similar analysis and a similar methodology may apply to any other compound that may be measured in the building environment (CO, PMx, VOC etc..). The analysis was performed for the demonstration period of the project and the reference values (aggregate statistics over the period as well as % of values above the threshold) are presented in the following table– metering data over 5 months (October 2021 – February 2022) (when data available).

5.6.1.3 Results

In the following table, the aggregate statistics for CO_2 content values are presented and compared, considering sample apartments among the ones monitored. Data for apartment L considers only two months (Jan 2022- Feb 2022), because it was not originally intended as part of the project and it was added following the engagement activities carried out. The results report the average value over the period, such as the percentage of values over the identified threshold.

Table 40 IAQ analysis in selected apartments

Apartment	Average IAQ (CO_2 ppm)	% Above threshold
apartment_L	450	0%
apartment_A	774	8.7%
apartment_I	791	9.8 %
apartment_G	898	12.3 %
apartment_H	616	< 1%
apartment_E	514	< 1%

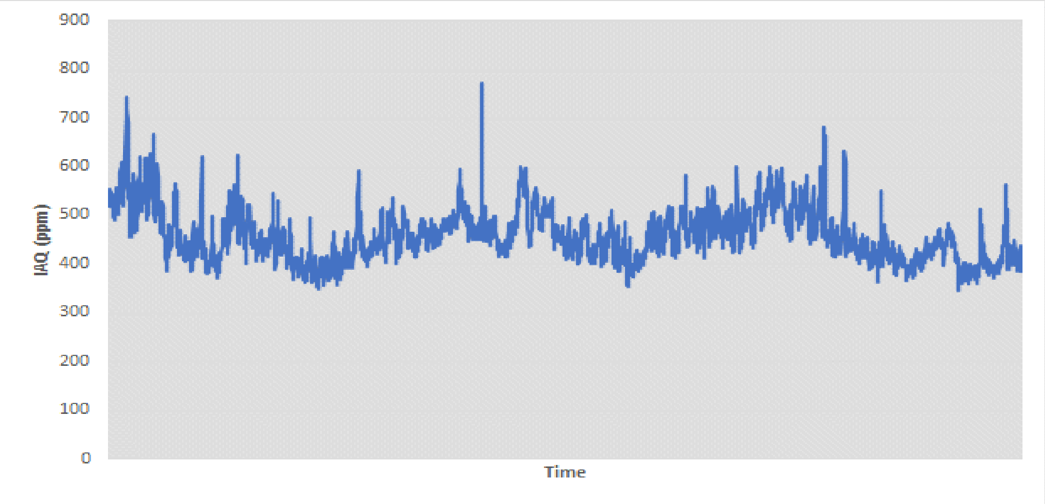


Figure 57 - Average indoor CO_2 content in a selected apartment

5.6.2 ENV 4 Greenhouse Gas (GHG) emission reduction

5.6.2.1 Introduction:

The aim of this KPI is to assess the amount of GHG emissions related to building energy consumption. The fossil fuel (natural gas) and electricity use are collected and then multiplied for the respective conversion factors.

5.6.2.2 Assessment methodology and baseline calculation

The fuel sources considered in the following analysis are the gas for winter heating and the electricity for the building's shared services (lighting, elevators, water pumps).
The baseline consumption refers to the measured consumption of the building during the heating season 2019-2020. Data were collected through energy bills The renovated scenario assumes a 38% energy saving for the heating service in accordance with chapter 5.4.1. No electric energy saving is considered in the renovated scenario.
The CO_2 emission factors are consistent with the Italian scenario and obtained from [Regione Lombardia, 2007] and [European Standard, 2008].

5.6.2.3 Results

The considered CO_2 emission for the baseline scenario was **162880 KgCO$_2$ eQ**, while in the renovated scenario is **106877 KgCO$_2$ eQ**, with a net improvement of **34%**.

Table 41 Equivalent CO_2 emissions – Baseline scenario

Fuel source	Consumption [kWh]	Conversion Factor [kg CO_2 eq/kWh]	CO_2 Emissions [kg CO_2 eq]
Natural Gas	737,621	0.1998	147,376
Electricity	35,790	0.4332	15,504

Table 42 Equivalent CO_2 emissions – Renovated Scenario

Fuel source	Consumption [kWh]	Conversion Factor [kg CO_2 eq/kWh]	CO_2 Emissions [kg CO_2 eq]
Natural Gas	457,325	0.1998	91,373
Electricity	35,790	0.4332	15,504

6 Conclusions

The presented document has the purpose to present the demonstration activity of the developed tools carried out in the Italian demonstration site in the Lombardy region, chosen for being representative of the south climate. A specific workflow has been followed for the demonstration to guide and support the cooperation between the different stakeholders and the tools developers.

Firstly, selected sensors were installed in 13 apartments chosen for their availability and different exposure and levels. Different kinds of issues have led to changes in what was initially programmed and stated in deliverable D8.1. The data collected by the sensors was used by some of the demonstration tools, including BIM4Occupants and BIMcpd, to evaluate the performance indicators.

The main activities were carried out during the implementation of the tools developed within the project to support an efficient renovation process of residential buildings.

All the demonstrations were successful in a way that the stakeholders could see the benefit of the tools to the renovation process. In general, feedback from professional users shows the ease of use of the tools, although technical assistance is not completely excluded. The increased data interoperability among the provided tools is also seen as a potential advantage for reducing time and costs. However, some tools, such as scanning and modelling tools, require both equipment and specific skills that require training and an increase in user competence attainable only with practice.

The BIM Management system (BIMMS) was demonstrated as the common data environment for the project storing building's BIM models, documents, sensors streaming, activities done at site, alerts and preferences of the inhabitants. It has demonstrated reliability and versatility in handling the various inputs from the process and provided by the various actors and data sources. Of all the tools, it is the closest to possible commercialisation. FAST MAPPING tool demonstrated the potential capabilities of the devices developed for mapping and scanning the built environment even if it requires a dedicated technical preparation of the users, such as the process of creating the IFC file on-site needs to be improved to increase the drafting speed.

BIMeaser simulated with great accuracy the existing energy performance, such as, of the renovated building, allowing both envelope and system solutions to be tested quickly, accurately and effectively. BIM4OCCUPANTS gave both the inhabitants and the owner the possibility to monitor the Indoor Environmental Quality of the apartments, such as an up to date information about the renovation works and the possibility to raise alerts. The possibility to have targeted environmental alerts through a dedicated function of the app could further improve the engagement of the inhabitants. BIMPlanner was used to monitor the activities at site using BIM-based location breakdown structure. The Italian demonstration project indicated some need for further development and possibilities for testing other planning scenarios, that includes different approaches for the management of the subactivities. The tool, along with BIMMS and BIM4Occupants demonstrated for sample apartments an occupant-centric approach for participative renovation planning. BIMCpd provided the building owner with the possibility to evaluate and monitor effectively the indoor performance of the renovated spaces, assessing comfort variables over a large period and comparing several apartments over the same time frame.

The tools developed can enable better design decisions during the renovation process that have an effect on the final planning and implementation. Better design enables not only better indoor environment quality comfort, but also a reduction of times and costs for the renovation process. However, the demonstration was limited and we cannot say that different stakeholders would not have achieved similar results with different processes and approaches, but we can say that the BIM4EEB project, developed an attractive and powerful BIM-based toolkit that can assist designers in the planning phase, contractors to efficiently perform the work, and service companies to provide innovative solutions for retrofitting buildings. In addition, using the BIM4EEB toolkit, stakeholders involved in the renovation process can improve semantic interoperability between their software and other software throughout the renovation process (design, planning, construction, operations, maintenance).

6.1 Lesson learnt

The relevance of stakeholders is a significant point outlined by BIM4EEB project. Different stakeholders are involved in the project and each of them has an important role within the renovation process, and in testing the developed BIM-based toolkit. A project aimed at digitizing construction sector methods and processes will require the proactive involvement of different stakeholders with different levels of digital knowledge or skills. Individuals involved in the process should be invited to dissemination activities. They should be introduced to use the tools and systems and engaged to become interested in them. Highlighting the new approach's advantages and increased possibilities should develop trusting relationships between them and the project.

In this sense, inhabitants are important figures in the demonstration activities. Different sensors have been installed within their apartments, and the inhabitants preferences and presence were fundamental for the choice and positioning of the devices.

Where possible, it's advisable to avoid sensors that have an important size and are quite noticeable in the apartment. Battery operated sensors should be preferred due to limited socket availability in the room.
Hubs and sensors that required an electrical plug were placed on user-owned furniture. This interference with the furniture was not always appreciated and required compromises in positioning, as well as demonstrating that occupants are inclined to tolerate a limited number of sensors in their apartment.
It's also advisable to have a network of a sensors under control and maintenance of the building owner, even if this requires internal dedicated resources. This approach reduces the need of involving users in monitoring the devices.

This improves the quality of the measured data and makes it possible to detect transmission problems immediately. However, alternatives that minimise the number of inspections and interventions inside the flats should be envisaged because of the difficulty in coordinating inspections and interventions with the availability of occupants. However, the management system must be able to guarantee the easy replacement and integration of damaged devices.

In the case of elderly inhabitants with limited digital knowledge, a longer introduction process like the one offered by Polimi and ALER is therefore necessary, defining periods of support and interaction, and data management assistance. A real-time alert and feedback system also enhances interaction and helps users in understanding the data collected.

The application of lean construction practices entails weekly or bi-weekly planning that should be actively supported by the general contractor and other stakeholders. An effective strategy involves a tool that supports the designer while also allowing flexibility in managing the structure of the activities and subactivities. This is particularly true when the process requires the presence at the site of sub-contractors assigned to dedicated tasks. The importance of providing this information to clients becomes even more pressing during uncertainty periods, such as the recent one we have been through when dealing with issues related to COVID-19 and shortages of construction materials, particularly in Italy. Formalizing the information flow and the framework is essential as well. This is unquestionably true if the added value of the up-to-date digital data of the site operations can be identified.

In the case of public tender procedures, it is therefore necessary to allocate resources to cover any extra operational costs arising from the management of information that may fall on the general contractor. This will be helpful to formalise the use of methods and systems since the very beginning.

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Annex I – Sensor positioning

The representative apartments in which the sensors have been placed were selected based on two main criteria:

- Residents' availability,
- diversification related to exposure and different levels of the building (low, medium, high/ stairs A and B).

Each apartment is identified by a number. Table 43 summarises the main characteristics of interest for the positioning of the sensors.

Table 43 Main characteristics of each apartment

Apartment number	Staircase	Floor	Apartment exposition	Type (2: two-room flat; 3: three-room flat)
A	A	Ground	East – West	3
B	A	Ground	East – West	2
C	B	Ground	East – West	2
D	B	Third	East – West	3
E	B	Third	East – West	2
F	A	Third	North – East – West	3
G	B	Sixth	East – West	2
H	A	Sixth	East – West	3
I	A	Seventh	East – West	3
L	A	Fifth	East – West	3
M	A	Seventh	East – West	2
N	B	First	East – West	3
O	B	Sixth	East – West	3

In Figure 58 and Figure 59 a floor plan is given with an indication of the exact locations of the sensors and some representative photos. Figure 60 presents the distribution of the sensors in the building

Figure 58 - Three rooms apartment – Sensor's positioning

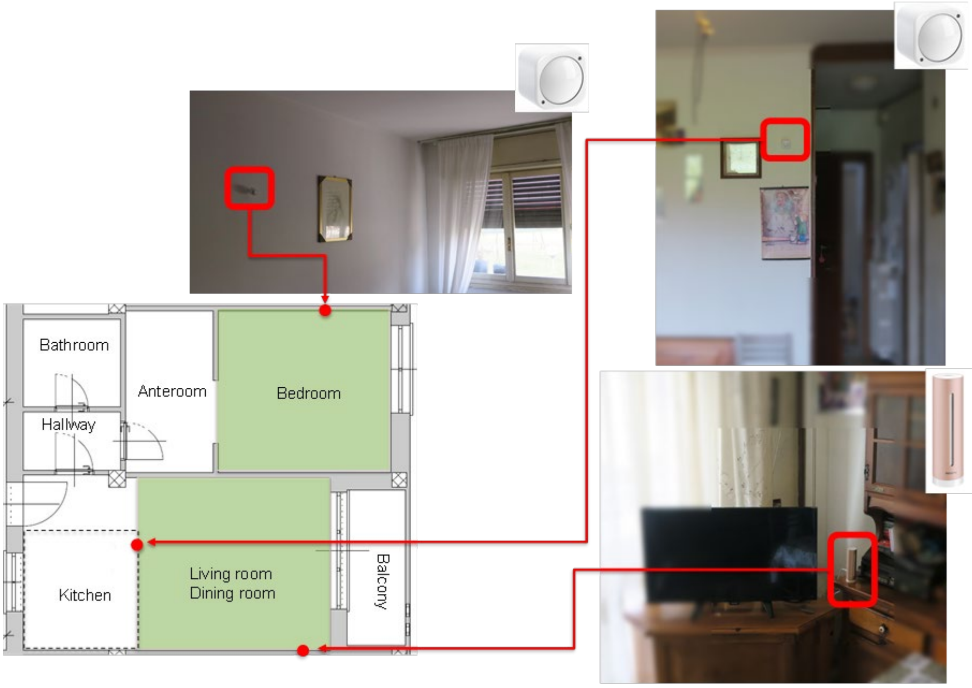

Figure 59 - Two rooms apartment – Sensor's positioning

Figure 60 - Distribution of the sensor in the building and per flat.

Annex II – List of the KPIs

Table 44 KPIs to be measured in Italian pilot site according to the tools.

Category of KPI	KPI	Name of the KPI	Italian site					
			BIMMS	Fast mapping tool	BIMeaser	BIM4Occupants	AUTERAS and BIMcpd	BIMPlanner
Renovation process	REP 1	Renovation Time Reduction	X	X[6]	X[7]		X	X
	REP 2	Renovation Cost Reduction	X		X			X
	REP 3	Actual/planned conformance - **time**		~~X~~	~~X~~			~~X~~
	REP 4	Actual/planned conformance - **cost**						X
	~~REP 5~~	~~Actual/planned conformance - **actions**~~			~~X~~			
	~~REP 6~~	~~Non-conformance Issues during inspection reduction~~						~~X~~
	~~REP 7~~	~~Time Reduction to fix quality issues~~						~~X~~
Comfort	COM 1	Adaptive Predicted Mean Vote (PMV)				(X)	X	
	COM 2	Predicted Percentage of dissatisfaction (PPD)				(X)	X	
	COM 3	Thermal discomfort factor				X		
	COM 4	Operative Illuminance				X		
	COM 5	Visual discomfort factor				X		
	COM 6	Average Indoor Noise Level				X		
	COM 7	Occupancy Profiling Accuracy				X		
Economic	ECON 1	Annual Cost Savings	X					
	ECON 2	Net Present Value (NPV)	X					
	ECON 3	Pay-back Period	X					
	ECON 4	ROI - Return on Investment			X			
	ECON 5	Life Cycle Cost (LCC)			X			
Energy performance	ENE 1	Energy Savings			X		X	
	ENE 2	Energy Savings (per building component)			X		X	
	ENE 3	Primary Energy Savings			X[8]		X	

[6] Time reduction on digital data acquisition and on BIM models creation
[7] Reduction on energy audit time and time reduction on decision-making for different renovation scenarios
[8] Reduction of net primary energy use

	ENE 4	Energy Performance Accuracy			X[9]		X	
	ENE 5	Total Use of Primary Energy			X		X	
Social	**SOC 1**	Ease of use for end users of the solution	X	X	X	X	X	X
	SOC 2	Beneficial for end-users	X	X	X	X	X	X
	SOC 3	Occupants active involvement in the renovation phase				X		
	SOC 4	Productivity improvement	X		X	X	X	X
	SOC 5	Improvement in collaboration among teams	X			X		
	SOC 6	Improvement in safety at construction site	X					X
	SOC 7	Level of intuitiveness in user applications	X	X	X	X	X	X
	SOC 8	Improved monitoring/access on information during renovation works	X	X				X
	SOC 9	Increased easiness in information exchange and tracking (data accessibility)	X	X			X	X
	SOC 10	Modular design and development of the BMS platform	X					
	SOC 11	Interoperability and data storage capability of BMS platform	X					
	SOC 12	Use of BIM in renovation business		X	X			
	SOC 13	Use of dynamic simulation tools for energy assessment			X			
	SOC 14	Integration of GIS data in BIM model for energy purpose						
	SOC 15	Development of digital logbooks for renovated building; management of as-built data in operational BIM models	X					
Environmental/safety	**ENV 1**	CO2/ CO compounds reduction					~~X~~	
	~~**ENV 2**~~	~~Particulate Matter (PM) reduction~~					~~X~~	
	~~**ENV 3**~~	~~Volatile Organic Compounds (VOC) reduction~~					~~X~~	
	ENV 4	GHG emissions reduction					X	
	~~**ENV 5**~~	~~Safety issues/ incidents/accidents (during inspection) reduction~~	~~X~~					

[9] Use of dynamic simoulation tools for energy assessment

Annex III – Additional time and cost analysis developed by the partners

BIMMS

TRADITIONAL		BIMMS		REP1 REP2
ACTIVITY - how it is done in the business-as-usual renovation?	**TIME**	**ACTIVITY - Tool method**	**TIME**	**%**
Use Case 0 Initiative: Preliminary decision for the renovation (go / no go decision)				
Data exchanged: by email with document attachments and through paper copies. No structured data about energy performance	2055 sec	The data required in Use Case 0 can be stored and shared in the BIMMS' CDE a) requirements can be shared as resource documensts b) sensors data streaming can be available in the BIMMS for the monitored apartments c) if cost and saving databases are available as Linked Data sources, they can be queried with the BIMMS' SPARQL Endpoint d) The BIMMS can store the OPR	565 sec	-73%
Use Case 1 Initiation: Renovation project initiation				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Initial geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC and shared all the times the model is changed: the workflow export, upload, download and import is time consuming	2055 sec	The data required in Use Case 1 can be stored and shared in the BIMMS' CDE, sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments	565 sec	-73%
Use Case 2.1 Concept Design: Quick calculation to find the design alternatives at conceptual level				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC and shared all the times the model is changes: the workflow export, upload, download and import is time consuming	2055 sec	The data required in concept design can be stored and shared in the BIMMS' CDE, Sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint, The BIMMS allows to manage the resources in compliancy with the ISO 19650 BIM Standard: versioning, status, classification	565 sec	-73%
Use Case 2.2 Preliminary Design: Preliminary energy simulations of the design alternatives				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC and shared all the times the model is changes: the workflow export, upload, download and import is time consuming	2055 sec	The data required in preliminary design can be stored and shared in the BIMMS' CDE, Sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint, The BIMMS allows to manage the resources in compliancy with the ISO 19650 BIM Standard: versioning, status, classification	565 sec	-73%

Figure 61 - Use cases and relevant activities: traditional process vs BIMMS (Part I) – Estimated

Use Case 2.3 Developed Design: More detailed energy simulation of the design alternatives				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Initial geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC and shared all the times the model is changes: the workflow export, upload, download and import is time consuming	2055 sec	The data required in developed design can be stored and shared in the BIMMS' CDE, Sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint, The BIMMS allows to manage the resources in compliancy with the ISO 19650 BIM Standard: versioning, status, classification	565 sec	-73%
Use Case 2.4 Detailed Design: More detailed simulation of the design alternatives				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Initial geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC, BIM Models must be exported in IFC and shared all the times the model is changes: the workflow export, upload, download and import is time consuming	2055 sec	The data required in Use Case 2.4 can be stored and shared in the BIMMS' CDE, Sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint, The BIMMS allows to manage the resources in compliancy with the ISO 19650 BIM Standard: versioning, status, classification	565 sec	-73%
Use Case 3 Construction: Implementation of the planned renovation measures				
Data exchanged by email with document attachments and no information about occupants comfort, indoor air quality and energy performance, Geometry information is often shared using CAD drawings instead BIM models, BIM Models must be exported in IFC and shared all the times the model is changes: the workflow export, upload, download and import is time consuming	2055 sec	The data required in Use Case 3 can be stored and shared in the BIMMS' CDE, Sensors data streaming (occupant's behaviour and indoor air quality) can be available in the BIMMS for the monitored apartments, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint, Resources can be linked (i.e. model entity with drawings\reports\specifications BIM Models, CAD drawings, reports and other construction documents can be stored, shared and managed in the BIMMS	565 sec	-73%
Use Case 4 Building Use: Operation and maintenance of the renovated building				
Data exchanged by email with document attachments, File sharing with no 3D Model viewer integrated, Critical data collection and data management due to the absence of a central repository	2055 sec	The data required in Use Case 4 can be stored and shared in the BIMMS' CDE, The BIMMS can store the as-build model, The digital logbook can store the updated operation and maintenance data, The BIMMS can store the OPR. OPR results are available via SPARQL Endpoint	565 sec	-73%

Figure 62 - Use cases and relevant activities: traditional process vs BIMMS (Part II) – Estimated

Traditional workflow	Time to complete	Run at once or multiple times	TIME	BIMMS workflow	Time to complete	Run at once or multiple times	TIME	%
Login to filesharing	5	1	5 sec	Login to BIMMS	5	1	5 sec	-73%
Create resource	40	1	40 sec	Create resource	60	1	60 sec	
Upload file for resource	20	1	20 sec	Upload file for resource	20	1	20 sec	
Set permissions	30	1	30 sec	Set permissions	30	1	30 sec	
Download BIM Model from the filesharing service	20	10	200 sec	Conversion time (BIM Models)	300	1	300 sec	
Conversion time (BIM Models)	120	10	1200 sec	Download BIM Model	20	1	20 sec	
Visualize on Viewer (BIM Models)	30	10	300 sec	Visualize on Viewer (BIM Models)	5	10	50 sec	
Upload BIM Model in the filesharing service	20	10	200 sec	Update BIM Model in the BIMMS (POST)	1	10	10 sec	
Change Revision \ Status	60	1	60 sec	Update BIM Model in the Authoring Tool (GET)	1	10	10 sec	
				Change Revision \ Status	60	1	60 sec	

Figure 63 - Traditional workflow vs BIMMS workflow – Estimated

ECON KPIs assessment focusing on BIMMS

The ECON KPIs can be calculated considering the costs and the values of the implementation of the BIMMS in a mid-size organization with a team composed of professional figures with competencies in the building sector and renovation works, like architects and engineers.
The BIMMS implementation considers the deployment in the organization premises with a deployment in an existing organization's IT infrastructure. The deployment can be also done in a cloud service, but due to high variability in the services offered on the market, and to simplify the baseline definition, only the deployment on-premises was considered.
The costs considered are the sum of hardware, software licenses, and IT maintenance and implementation services. The costs are calculated as the average of the current availability and can be subject to changes not dependent on the authors.

		BIMMS - Costs to implement (prices in euros)	Mid-range	Low-range
Hardware	a	Server	6000	3000
Software	b	Microsoft Windows Server Standard	2000	2000
Software	c	Openlink Virtuoso Server Workgroup	1000	1000
Services	d	Configuration, Maintenance, Other (1st year)	3000	3000
Services	e	Maintenance	1500	1500
Total	F	a+b+c+d	12000	9000
Total for 5 years	G	F+(c+e)*5yr	22000	14000
Cost per year*	H	G / 5yr	4400	2800

The server configuration is able to support up to 50 users (mid-range) or 30 users (low-range), and differs in CPU, RAM and Disk space availability. The BIMMS is considered in use at least for 5 years, without major updates in hardware configurations. The total cost for 5 years considered the total costs for the first year (with a server, software, and full implementation services) and a year ownership fee composed of the

software license subscription (Openlink Virtuoso for 1000 euros) with a reduced service maintenance fee that considers only IT maintenance (esteemed in 1500 euros).
As a reference, other CDE platforms available on the market offer monthly and yearly SaaS solutions. The functionalities, features and tools included can differ significantly from the BIMMS. The costs do not include discount prices.

Users per year(s)	Autodesk BIM 360 Docs	Kroqi (CSTB) Enterprise	Comparison with BIMMS MID-Range Server
1 user \ 1 year	530	12	n.a.
20 users \ 1 year	10600	2880	2800 (low-range)
30 users \ 1 year	15900	4320	4400 (mid-range)
1 user for 5 years	2650	60	n.a.
20 users for 5 years	53000	14400	14000
30 users for 5 years	79500	21600	22000
			Prices in euros

To calculate the values of baseline and current costs was took into consideration the data published in the report “The architectural profession in Europe 2020 – A sector study” authored by the Architects’ Council of Europe. (source: https://www.ace-cae.eu/fileadmin/user_upload/2020ACESECTORSTUDY.pdf - https://www.ace-cae.eu/activities/publications/ace-2020-sector-study/)The report gives a picture of the average earnings and revenue of the architects that can be used to calculate the baselines and current esteem costs and savings included in the formulas.

ECON 1 Annual Cost Savings
Reduction of cost due to the renovation activities; compared to the baseline values

$$CS = \left(1 - \frac{CS_C}{CR_E}\right) x100$$

CS_c: The actual operational cost post renovation

CR_E: The baseline operational cost (before BIM4EEB interventions)

The KPI ECON1 - Annual Cost Saving can be calculated considering the cost saved by the time reduction that occurred during the renovation phases. The result considered the activities done by an architecture practice leading a renovation work, as a lead architect that supervises the design and construction phases. To calculate the reduction time was simulated a typical workflow that considers a team of users working together using the BIMMS. The BIMMS functionalities allow to update of the design resources to avoid repetitive and time-consuming tasks like the export-upload-download-import chain. The results of the tests indicate a reduction time of up to 70% when the data exchange does not include changes in geometries. The KPI is calculated assuming that the costs savings can be related directly to the reduction time.

- the average practice revenue (1)
- the average practice profits (2)
- the average practice charge for services (3)
- the cost to implement the BIMMS in 5 years.
- The discount rate = 3.3%
- A reduction time percentage more conservative estimated at 30%, considering a different kind of activities that involves the architect

Sources:
(1) https://www.ace-cae.eu/fileadmin/user_upload/2020ACESECTORSTUDY.pdf Paragraph 3.3 pag 40
(2) https://www.ace-cae.eu/fileadmin/New_Upload/7._Publications/Sector_Study/2018/2018__ACE_Report_EN_FN.pdf Paragraph 3.6 pag.41
(3) https://www.ace-cae.eu/fileadmin/user_upload/2020ACESECTORSTUDY.pdf Table 3-5, pag.41

Italy average practice revenue (1)

- 3 to 5 staff = 115783 €/yr
- 6 to 10 staff = 385514 €/yr
- 10 to 30 staff = 1015186 €/yr *

* value extrapolated from the database in (1) through a polynomial regression

Italy the average practice profits percentage (2)

- 3 to 5 staff = 72%
- 6 to 10 staff = 71%
- 11 to 30 staff = 70%

Italy practices percentage charges per kind (3)

- Per cent per contract value: 36%
- Lumo sum: 38%
- Hourly charge: 6%
- No charge agreed: 6%
- Other methods: 21%

Italy profit related to Hourly charged activities:

- 3 to 5 staff = 115783 €/yr x 72% x 6% = 5000 €/yr
- 6 to 10 staff = 385514 €/yr x 71% x 6% = 16422 €/yr
- 11 to 30 staff = 1015186 €/yr x 70% x 6% = 42637 €/yr
-

Annual cost savings related to the use of BIMMS

- 3 to 5 staff = 6947 €/yr x 30% reduction time = 1500 €/yr
- 6 to 10 staff = 23130 €/yr x 30% reduction time = 4926 €/yr
- 11 to 30 staff = 60911 €/yr x 30% reduction time = 12791 €/yr

This conservative estimate of the time and cost optimisation arises from the portion of revenue charged to the customer by the hour. Generally, this is the portion that is most easily identifiable and that normally has a more effective monitoring process. Only the profit was considered, as the part that could be reinvested.

ECON 3 Pay-back Period

Type: Time (years)
The period required to recover the funds expended in investment on renovation.

$$Payback\ Time = \frac{C_{INV}}{S}$$

C_{inv} = Capital Invested [€];

S= payback/earnings or savings in an annual period [€/year];

Payback time

- Mid-Range Server - Payback for practice (2 to 5 staff) = 22000/1500 = 14.6 yr
- Mid-Range Server - Payback for practice 11 to 30 staff = 22000/12791 = 1.79 yr
- Low-Range Server - Payback for practice (2 to 5 staff) = 14000/1500 = 9.3 yr
- Low-Range Server - Payback for practice 11 to 30 staff = 14000/12791 = 1.09 yryr

ECON 2 Net Present Value (NPV)

Calculated based on nominal costs and discount rate based on the projected actual future costs to be paid, including general inflation and deflation.

$$NPV = \sum_{n=`1}^{N} \frac{C_n}{(1+d)^n} - C_a$$

C_a = Initial Investment

C_n = The annual savings in a year, n;

d = investment rate

n= Years of investment

Low-Range Server – NPV for **practice 2 to 5 staff**

Discount rate	3.3%
-9000	01/01/2022
1500	31/12/2022
-2500	01/01/2023
1500	31/12/2023
-2500	01/01/2024
1500	31/12/2024
-2500	01/01/2025
1500	31/12/2025
-2500	01/01/2026
1500	31/12/2026

Mid-Range Server – NPV for **practice 2 to 5 staff**

Discount rate	3.3%
-12000	01/01/2022
1500	31/12/2022
-2500	01/01/2023
1500	31/12/2023
-2500	01/01/2024
1500	31/12/2024
-2500	01/01/2025
1500	31/12/2025
-2500	01/01/2026
1500	31/12/2026

- 11'414.70 €	NPV

Low-Range Server – NPV for **practice 11 to 30 staff**

Discount rate	3.3%
-9000	01/01/2022
12791	31/12/2022
-2500	01/01/2023
12791	31/12/2023
-2500	01/01/2024
12791	31/12/2024
-2500	01/01/2025
12791	31/12/2025
-2500	01/01/2026
12791	31/12/2026

39'856.72 €	NPV

- 14'414.70 €	NPV

Mid-Range Server – NPV for **practice 11 to 30 staff**

Discount rate	3.3%
-12000	01/01/2022
12791	31/12/2022
-2500	01/01/2023
12791	31/12/2023
-2500	01/01/2024
12791	31/12/2024
-2500	01/01/2025
12791	31/12/2025
-2500	01/01/2026
12791	31/12/2026

36'856.72 €	NPV

Fast Mapping Toolkit

ALER		Fast Mapping		REP1
ACTIVITY - how it is done in the business-as-usual renovation?	**TIME**	**ACTIVITY - Tool method**	**TIME**	**%**
Use Case 1 Initiation: Renovation project initiation				
Measure of a small number of apartments in order to verify the correctness of the drawings Assumption: 2 workers, 3 working days, 3 apartments + common spaces (8 hours each apartment)	8 hours	The toolkit helps to provide a visualization of the existing building. The geometric data are obtaind by a laser scan. The laser scan result in a point cloud of the considerd room.	45 min	-70%
Measure of common spaces	24 hours		Estimated same time reduction of the previous activity	-70%
Measurement of the missing parts, if needed	32 hours		Estimated same time reduction of the previous activity	-70%
Identification of the position of electrical systems and other constraints from site survey and only for common parts	-	By using the sensor stick, it is possibly to detect capacitance, inductance, electricity and temperature in the walls. Depending on the purpose with the mapping these properties are possibly to present in the HoloLens2 by boxes. The time is considered for apartment	42 min	-
The interior of the apartments is undetectable from the point of view of the positioning of the electrical and gas systems.	16 hours			
	-	The point cloud are downloaded to the companion app in order to make it visible in the HoloLens2 Once the point cloud is in the HoloLens 2, its possibly to define the walls, winow, doors etc. All objects are defined as boxes.	42 min	-
Use Case 2.1 Concept Design: Quick calculation to find the design alternatives at conceptual level				
Creation of CAD drawings if not available For a standard project	100 hours	The visualisation can help to understand how the different options will look like, The fast mapping gives in first place information about existing construction. But its possibly to add boxes on other places. What is difficult is to remowe things.	The fast mapping will only create an ifc-file. Creation of a CAD drawing out of the scope of the tool	-
Creation of a BIM model from the CAD drawings	100 hours			

Figure 64 - Use cases and relevant activities: traditional process vs Fast Mapping toolkit - measured and estimated

BIMeaser

ALER		BIMeaser		REP1
ACTIVITY - how it is done in the business-as-usual renovation?	**TIME**	**ACTIVITY - Tool method**	**TIME**	**%**
Use Case 0 Initiative: Preliminary decision for the renovation (go / no go decision)				
Collection of information (drawings, bills, previous interventions) about the building from the database Analysis of different technical solutions adopted by the owner in past projects First evaluation of possibilities of intervention according to the economic availability and the status of the building The decision to carry out an extraordinary maintenance intervention (and in this case also the energy refurbishment is included) is dictated by the availability of resources in comparison between the state of a building in relation to all the assets (order of priority) Heritage database with reference to experience (continuous inspections every 60 days) carried out by technical employees	80 hours	Condition surveys and current performance (energy audit) of the building analysed by the energy expert, National renovation measure database helps to find reasonable renovation measures from existing measure history	72 hours	-10
Use Case 1 Initiation: Renovation project initiation				
Setting of the performance target according to the budget available There are no "direct" objectives related to consumption but the response to maintenance needs and adaptation to the legislation in force Start of the activities of energy modelling through CAD or an excel file Calculation of consumption of previous years from gas bills Documentation of feasibility analysis for financing	80 hours	Performance based design methodology guides the design team to set clearly defined target range of OPR's according to the owners sustainability targets (energy, cost, comfort)	72 hours	-10
Use Case 2.1 Concept Design: Quick calculation to find the design alternatives at conceptual level				
Design of the solution and creation of the drawings with the chosen solution Based on the experience of ALER's Technical Office in reference to traditional and consolidated technical solutions	36 hours	The first design session with the design team BIMeaser receives the IFC and other required information from BIMMS (ideally automatically, but currently only partly implemented because TRL6) National renovation database updated, if the existing measures are not suitable The before the renovation state of the energy model is calibrated to be inline with the historical consumption Different measures are compiled as scenarios and simulated using BIMeaser The review of the conceptual energy saving scenarios and their OPR's are made. A check that resulted OPR's are inline with the owners constraints (e.g. max. cost, max. CO2-emissions, min RES share, max. payback time, max. specific energy consumption, summer thermal comfort) Results are returned to BIMMS	9 hours	-75

Figure 65 - Use cases and relevant activities: traditional process vs BIMeaser tool (Part I) - Measured

Use Case 2.2 Preliminary Design: Preliminary energy simulations of the design alternatives				
Preliminary project documentation (referring to the state of the sites and an estimated cost) for financing Preliminary project pursuant to the "Procurement Code and Regulations"	100 hours	The second design session with the design team using the more elaborated BIM and first ideas of the product level technical data (e.g. window U-value, insulation type, COP of the heat pump) of the renovation measures are known National renovation database updated with the product level energy efficiency data, improved IFC and other required information from BIMMS (ideally automatically, but currently only partly implemented because TRL6) The energy scenarios are simulated again with the added information using BIMeaser The review of the more detailed scenarios and their OPR's are made. A check that resulted OPR's are still inline with the owners constraints (e.g. max. cost, max. CO2-emissions, min RES share, max. payback time, max. specific energy consumption, summer thermal comfort) Results are returned to BIMMS Results are communicated to the project owner who selects the option for implementation	9 hours	-75
Use Case 2.3 Developed Design: More detailed energy simulation of the design alternatives				
Developed project documentation for internal approval and subsequent building permit request Developed project pursuant to the Procurement Code and Regulations	400 hours	Latest model is always available in BIMMS The energy model could further be used in the design phases to check that the design is on the track. This is important part of the performance based design, where the technical design selections are checked against the higher level targets (OPR's in this case) in each design stage before proceeding to the next stage. This feature is out of the scope of the BIM4EEB implementation of BIMeaser tool, which is focusing on the early design stage	Out of the scope of the tool	-
Use Case 2.4 Detailed Design: More detailed simulation of the design alternatives				
Documentation of the detailed project for internal approval and subsequent work award procedure (tender) Detailed project pursuant to the Procurement Code and Regulations	200 hours	Latest model is always available in BIMMS and enables digital twin support for the O&M planning	Out of the scope of the tool	-
Use Case 3 Construction: Implementation of the planned renovation measures				
Development of final reports and maintenance plan The detailed project will be updated at the end of the works (as carried out) by the Director of Works and by the Contractor with the drafting of the Technical File / Maintenance Plan of the Work in accordance with current legislation (Procurement Code and Regulations, Safety Regulations).	50 hours	Latest model is always available in BIMMS and can untilised for performance test plan	Out of the scope of the tool	-
Use Case 4 Building Use: Operation and maintenance of the renovated building				
Obtaining bills for an interval of time Calculation of baseline energy values Obtaining simulation results from design stage Check between simulation results and consumption registered from bills in excel Communication via e-mail Operation checks are performed in the testing phase. Consumption data will be available at the end of the first operating season, therefore approximately 1 year	1 week	Latest model is always available in BIMMS and can be used in model based management and control. It would be a extremely nice feature to have a digital twin of the energy model, which could be used during the operational phase. This is far beyond the scope of BIM4EEB implementation of BIMeaser.	Out of the scope of the tool	-

Figure 66 - Use cases and relevant activities: traditional process vs BIMeaser tool (Part II) Measured

AUTERAS

TRADITIONAL		AUTERAS		REP1
ACTIVITY - how it is done in the business-as-usual renovation?	**TIME**	**ACTIVITY - Tool method**	**TIME**	**%**
Use Case 2 Design				
Import of the IFC-structure	1 min	Import of the IFC-structure	1 min	-84%
Evaluation of functional user requirements. The client is interviewed for every trade	45 min	Evaluation of functional user requirements	30 min	
Generatation of standardized RAS-scheme (manual labour)	120 min	Generatation of standardized RAS-scheme automatically and check of validity	1 min	
-Search for suitable devices -Check of interoperability (manual labour)	120 min	Survey of devices which realize the RAS-scheme: - automatic search in AUTERAScatalog for suitable devices - check interoperability	15 min	

Figure 67 - Use cases and relevant activities: traditional process vs AUTERAS - Estimated

BIMPlanner

ALER		BIMplanner		REP1
ACTIVITY - how it is done in the business-as-usual renovation?	**TIME**	**ACTIVITY - Tool method**	**TIME**	**%**
Use Case 3 Construction: Implementation of the planned renovation measures				
Communication of the schedule with construction management office (ufficio direzione lavori) by e-mail and phone calls. Recurrent event, timing assessed considering the total time of intervention	200 hours	Time needed in planning and progress tracking · BIMPlanner support detailed short term (2-6wk) detailed scheduling and progress tracking	140 hours	-30%
Tracking of activities during works by project manager (direttore lavori)	160 hours	Time needed for construction work · Timing of activities is planned and tracked by work location · Location based detailed scheduling of activities enables less lead time and more accurate monitoring	80 hours	-50%

Figure 68 - Use cases and relevant activities: traditional process vs BIMPlanner tool -Estimated