Pilot Planning and Setup

v2

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Pilot Planning and Setup v2

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Authors List

Leading Authors				
First Name		Last Name	Beneficiary	Contact e-mail
Stavros		Koltsios	CERTH	skoltsios@iti.gr
Nikos		Katsaros	CERTH	nkatsaros@iti.gr
Co-Author(s)				
#	First Name	Last Name	Beneficiary	Contact e-mail
1	Panagiota	Chatzipanagiotidou	CERTH	phatzip@iti.gr
2	Dimos	Ioannidis	CERTH	djoannid@iti.gr
3	Christiana	Panteli	CLEO	c.panteli@cleopa.de
4	Phoebe-Zoe	Georgali	FRC	res.gp@frederick.ac.cy
5	Paris	Fokaides	FRC	eng.fp@frederick.ac.cy
6	Gerfried	Cebrat	SEC	Gerfried.Cebrat@senercon.de
7	Christos	Kontopoulos	GSH	c.kontopoulos@geosystems-hellas.gr

Reviewers List

Reviewers			
First Name	Last Name	Beneficiary	Contact e-mail
Naghmeh	Altmann	AEA	Naghmeh.Altmann@energyagency.at
Mija	Susnik	DMO	mija@demobv.nl

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Executive Summary

The current report (D5.7) comprises the second and final version of the D^2EPC Pilot Planning and Setup. The aim of this document is to provide a thorough description of the status of the pilot sites concerning the demonstration of the D^2EPC solution and present the necessary actions taken, which preceded the deployment of the business scenarios and the corresponding use cases. The deliverable also outlines the business mapping upon the project's pilots, describing the involved stakeholders.

A thorough analysis of the six pilot sites is carried out. The buildings' physical topology and enclosing envelope are studied, along with the installed equipment, which constitute an important data source for the necessary calculations for the asset-based and the operational-based EPC. This information, which was also included in the first version of the deliverable, is now updated with the final details for each case study.

Additionally, an assessment of the buildings concerning the up-to-date EPC rating and the SRI score is documented. This process revealed the current buildings' condition in terms of energy efficiency and smart readiness and served as a comparison base to evaluate the results that the D^2EPC tools produced.

Finally, a summary of the case studies is provided, pinpointing the anticipated risks as well as any issues that occurred during their preparation and the corresponding mitigation actions that were performed.

This final version of the deliverable presents the final status of the pilot sites, including any changes that have been applied towards successfully finalizing the deployment of the D^2EPC solution and concluding the work under T5.2.

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List of Acronyms and Abbreviations

Term	Description
AC	Air condition
API	Application Programming Interface
BAPV	Building Applied Photovoltaic
BIM	Building Information Modelling
BMS	Building Management System
BS	Business Scenario
DHW	Domestic Hot Water
DIH	Digital Innovation Hub
DSL	Digital Subscriber Line
EPC	Energy Performance Certificate
ESCO	Energy Service Company
ESS	Energy Storage System
GDPR	General Data Protection Regulation
HVAC	Heating, cooling, air-conditioning
IoT	Internet of Things
LCA	Life-Cycle Assessment
LED	Light-emitting diode
nZEB	near Zero Energy Building
PV	Photovoltaic
PVC	Polyvinyl Chloride
RES	Renewable Energy Sources
UC	Use Case
VRF	Variable Refrigerant Flow

1 Introduction

1.1 Scope and objectives of the deliverable

This report demonstrates the pilot sites that have been used as test-beds for the implementation of the D^2EPC methodology framework. Firstly, the reader is familiarized with the framework through the presentation of the D^2EPC pilots' business-oriented aspects. A thorough analysis of each pilot building reveals the required information according to the methodology, that the several D^2EPC components utilize to calculate the building's overall energy performance. This information has been updated in this second version of the deliverable in alignment with the project's progress. Additionally, the hurdles, which were identified during the aforementioned process, and the measures taken to tackle them and ensure the application of the proposed solution are documented.

1.2 Structure of the deliverable

To cover all the above-mentioned aspects, the report is structured as following:

- **Chapter 2** introduces all the various Personas / Users' engagement / business scenarios / technical use cases.
- **Chapter 3** gives an overview of the pilot buildings studied within the project and provides general information.
- **Chapters 4-9** present in detail the characteristics of the six pilot buildings. A common structure is used for the description of each building. In particular, the provided information concerns the buildings' topology, the elements that comprise the building envelope, as well as both the systems used for covering the energy needs and the sensing equipment that collects the various measurements.
- **Chapter 10** sums up the information gathered for the pilot sites and focuses on special points and issues identified throughout the examined case studies.
- **Chapter 11** sums up the main conclusions and findings of this deliverable, and the next steps for the subsequent deliverables.

1.3 Relation to Other Tasks and Deliverables

This report documents the preparation towards the pilot realization of the D^2EPC methodology deployment in real life conditions. The methodology implementation on the pilot buildings follows the scheme described in the Deliverable 1.9 "D^2EPC Framework Architecture and specifications v3". Additionally, it presents in detail aspects and activities addressed within Task 3.1 "IoT and BMS interfaces to extract energy related data", where a detailed description of the existing infrastructure was documented in D3.4 "D^2EPC Platform & Interfaces v2". Finally, this task is closely related to Work Package 2, as well as, with the Asset and Operational methodologies, developed within the Task 5.1 "D^2EPC guidance for auditing and implementation". The required inputs from the methodologies define the information that should be included in the pilots' descriptions. Finally, this deliverable has a close relation with D5.8 "D^2EPC Pilots Demonstration v2", which leverages the preparation work performed to boost the application of the D^2EPC solution to the Case Studies.

2 D^2EPC Business Mapping upon Pilots

2.1 D^2EPC Personas

The D^2EPC platform is planned to engage the following stakeholders:

- **D^2EPC Platform Developer/ Administrator:** The team of people responsible for the platform's operation. Their main concern is to identify and solve the issues that emerge in the platform, as well as, to ensure that it is aligned with the regulations in effect through frequent updates.
- **EPC Designer/ Auditor:** The person responsible for the issuance of the EPC, who has an engineering background and additionally is qualified according to the D^2EPC standards.
- **Owner:** The owner of the property or multiple properties, which are managed under common access from one digital place.
- **Tenant of a building:** Besides the owner in the D^2EPC schema the tenants of the building also have access to the platform. They receive useful information regarding the asset, such as the energy consumption, the current EPC rating etc., as well as personalized suggestions towards encouraging their engagement in the increase of the building efficiency.
- **Facility Manager:** In the case of larger buildings, facility managers also have the opportunity to access the platform and to monitor the asset's operational condition, its maintenance needs or acquire certain fields of information (e.g. equipment datasheets).
- **Building Material/ Construction/ Services Industry:** Industry stakeholders have the ability to insert information about their services or products in the platform.
- **Real Estate Agencies, Financial Institutions/ Banks:** They can have a general overview of the building market in terms of energy efficiency. Such information may assist their decision-making process in various ways.
- **Authority, Policy Makers, Registries (b-Logbooks, Digital Passports):** They can have access to aggregated data that may contribute to the redefinition or the update of the current policies for the decarbonization of the building sector.
- **Utilities, ESCOs:** Similarly to the industry stakeholders, utilities can upload characteristics about their services on the D^2EPC platform (e.g., energy pricing policies). Furthermore, they can have access to the energy consumption data of their customers.

2.2 Business Scenarios and Use cases

The D^2EPC project aims to modernize the energy certification processes in a digital and dynamic way. The proposed certification procedure has been mapped to a set of business scenarios and their relevant use cases. The implementation of the developed methodology in the pilot buildings was expected to be carried out in such a way that covers the entire spectrum of the business scenarios along with their respective Use Cases. Further information about the scope of each BS and UC can be found in D1.9 “D^2EPC Framework Architecture and Specifications v3”.

The cross matching of each pilot building with the relevant BS and UC has been carried out under Task 5.3 and presented in D5.8 “D^2EPC Pilots Demonstration v2”.

Table 1: D^2EPC Business Groups, Business Scenarios and Use Cases

Business Group A: Issuance of Energy Performance Certificates	
BS1	Definition of buildings energy class and whether minimum requirements are met for Asset Rating
UC1.1	Extract and Verify Data from BIM
UC1.2	Issue a D^2EPC asset EPC
UC1.3	Issue an SRI report
UC1.4	Asset Rating Indicator Assessment Report (LCC, LCA)
UC1.5	Provide Design recommendations for performance improvements
UC1.6	Asset Rating as a service
BS2	Definition of buildings energy class and whether minimum requirements are met for Operational Rating
UC2.1	Extract and Verify Data from Measurements for the Digital Twin
UC2.2	Issue a D^2EPC operational EPC
UC2.3	Operational Rating Indicator Assessment Report (LCC, HC&W)
UC2.4	Provide Operational recommendations for performance improvements
UC2.5	Operational Rating as a service
Business Group B: EPC Monitoring, Evaluation & Recommendation	
BS3	Provision of (near) real-time building information, deviations, and recommendations
UC3.1	Provide (near) real-time building information
UC3.2	Provide information on as-designed/in-operation deviations
UC3.3	Provide regular recommendations for improving operational energy performance & conditions in terms of health and comfort.
Business Group C: Evaluation and Benchmarking of more certificates for policy making / marketing / business purposes	
BS4	Provision of regional level of EPC statistics for third party stakeholders
UC4.1	Regional Level Visualisation of dynamic (aspect of time) energy performance information for asset-based EPCs
UC4.2	Regional Level benchmarking and statistics comparison between regions
UC4.3	Building performance statistics for operational rating of pilot buildings and 3d visualisation
BS5	Provision of dEPC statistics related to materials, assets, etc. for promoting “greener” equipment campaigns
UC5.1	Provision and Visualization of correlation of building materials and energy performance
UC5.2	Provision and Visualisation of correlation of building assets/systems and energy performance

3 Overview of D^2EPC Case Studies

The development of an assessment framework for the European building stock requires a wide range of pilot buildings with different operational, architectural and technical characteristics. The D^2EPC project has at its disposal six pilot buildings, namely, the nZEB Smart House DIH in Thessaloniki, Greece (Case Study 1); a residential multi-family building in Velten, Germany (Case Study 2); a tertiary building in Berlin, Germany (Case Study 3); the new wing building of Frederic's University in Nicosia, Cyprus (Case Study 4); and two multi-family buildings located in Berlin (Case Studies 5 and 6). The plethora of characteristics in this set of pilot buildings have set a challenging environment for the applicability and validity of the under-development EPC methodology.

The two main factors that differentiate each pilot are the operational type (use) and its location. Regarding the use type of each building, there are case studies that belong to the residential sector but also to the tertiary one. Furthermore, certain pilots have mixed uses (e.g. concurrent residential and office usage can be found in the case of nZEB Smart House), allowing the methodology's validity to be tested in more complex cases. As the pilots are located in three different countries (Greece, Cyprus, and Germany), the methodology can be examined in various scenarios in terms of climate conditions, building constructions, and user preferences (e.g., comfort conditions or end-goals). Lastly, the EPC results can be compared with the respective values derived from the building EPC assessment according to the national or regional rating methodologies.

4 Case Study #1: nZEB Smart House DIH

The first pilot building is located in Thessaloniki, Greece and is owned by CERTH. The advanced building infrastructure, both in terms of energy-efficient technical systems and extended IoT installation, establish its role as a fertile testbed to try out the methodologies developed within D^2EPC. The already existing plethora of data/ measurements and information can be used to give insights into its operational characteristics.

Figure 1: nZEB Smart House

4.1 Objectives and Scope

CERTH's nZEB Smart House is a duplex apartment, representative of a single-family residential building, and is already equipped with many IoT, Smart Home solutions that provide a lot of information about its operational characteristics. The construction of the building started in 2014 and was completed in 2016. Typically, the building has no actual residents, since it functions as an office during the usual office hours. However, except for the specific rooms that are officially used as offices (Control Rooms) the building has also common residential rooms such as a living room, bedrooms etc. equipped with IoT devices.

4.2 Topology

The house consists of two floors and has a total area of 317.7 m^2. More specifically, the ground floor has an area of 182.7 m^2 and the first floor has an area of 135 m^2. People can enter the building both by the ground floor and the first floor (by using an external winding staircase). The two stories are connected internally by a staircase, while there is also an elevator.

The nZEB Smart House includes a total number of 14 rooms divided into two main categories (thermal zones) according to their use. The control rooms on the ground floor along with the demo room on the first floor are included in the "office" category. The central space on the ground floor (living room, kitchen, bedroom) and the rest of the first's floor area are included in the "residential" zone category. Lastly, the engine room on the first floor is considered an unoccupied space. Each room has a plenum space or "acoustic ceiling", at an elevation of 2.6 meters above the floor level, which is also included in the zone of unoccupied spaces.

The ground floor includes two office spaces on the east and west sides of the floorplan as presented in Figure 2. Furthermore, the machinery room that is also located on the ground floor is considered a non-heated space. The first floor includes two office spaces on the west and south sides while the rest of the floorplan consists of two bedrooms, a bathroom and circulation spaces, as shown in Figure 3. The above-described distinction have facilitated at a later stage the thermal study of the building.

Table 2: Zones of the nZEB Smart House

Zone	Spaces
Office	Control Room East, Control Room West (+WC), Demo Room
Residential	Living room, Kitchen, Guest Room, WCs, Single Bedroom, Double Bedroom, Game Room, Bathroom, Halls- Staircase
Unoccupied	Plenums, Engine Room

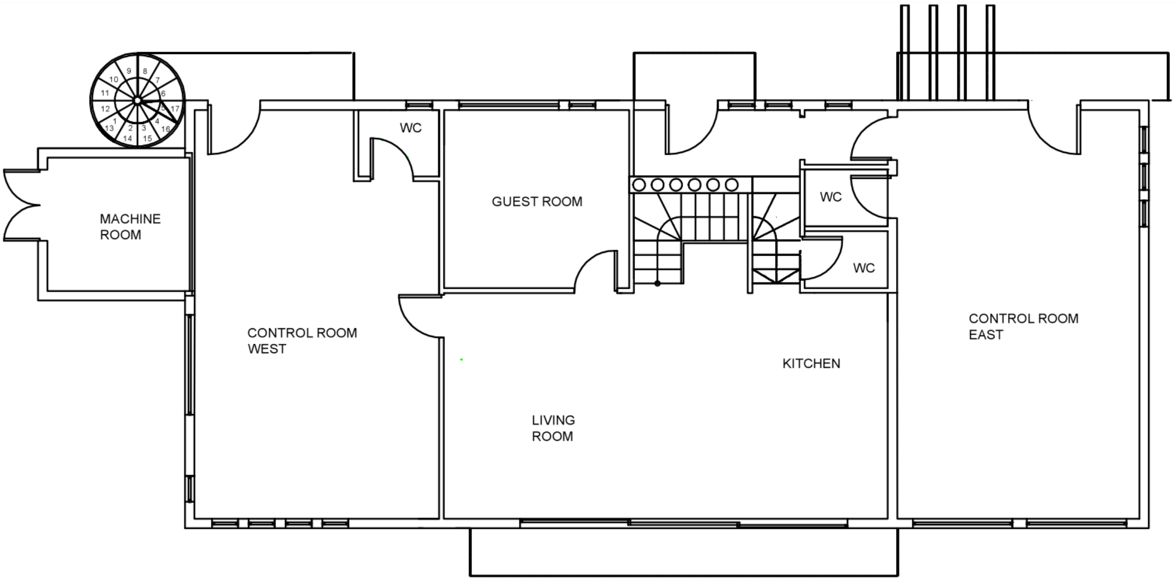


Figure 2: Ground floor plan

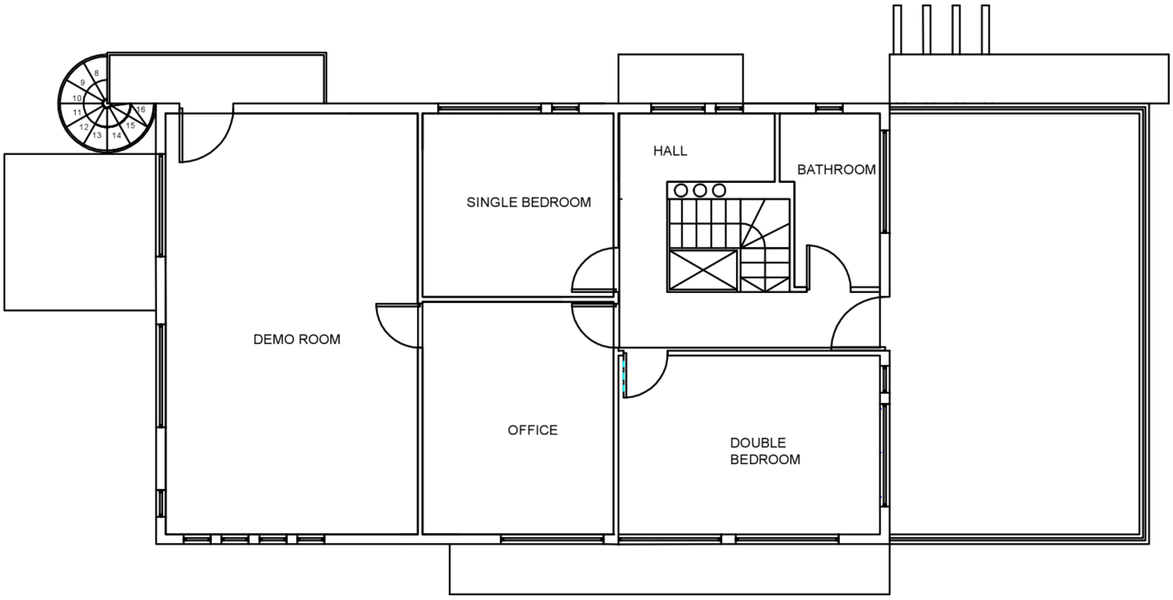


Figure 3: First floor plan

A photorealistic representation of the house is demonstrated in Figures 4-8. The presentations derive from the IFC file 3-D visualization in a BIM environment.

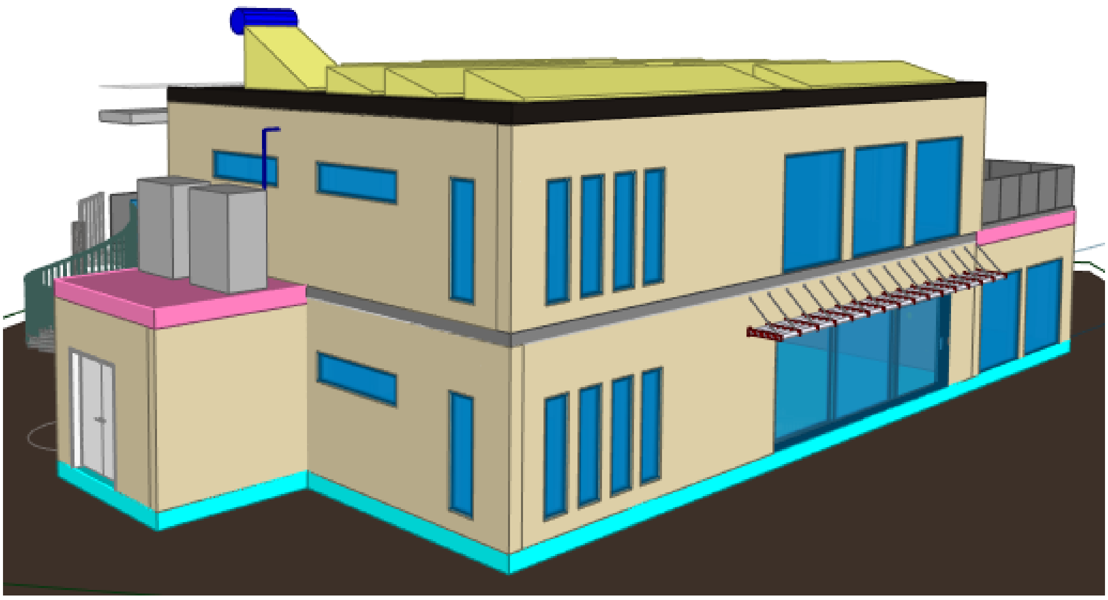


Figure 4: South - West view of Smart House building

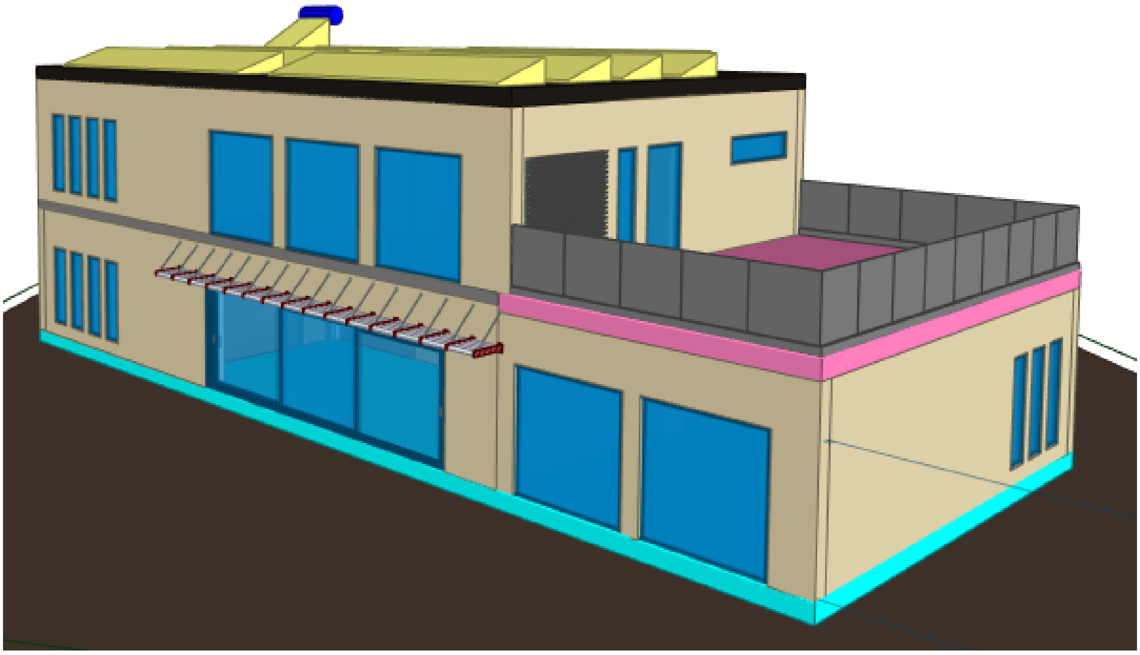


Figure 5: South - East view of Smart House building

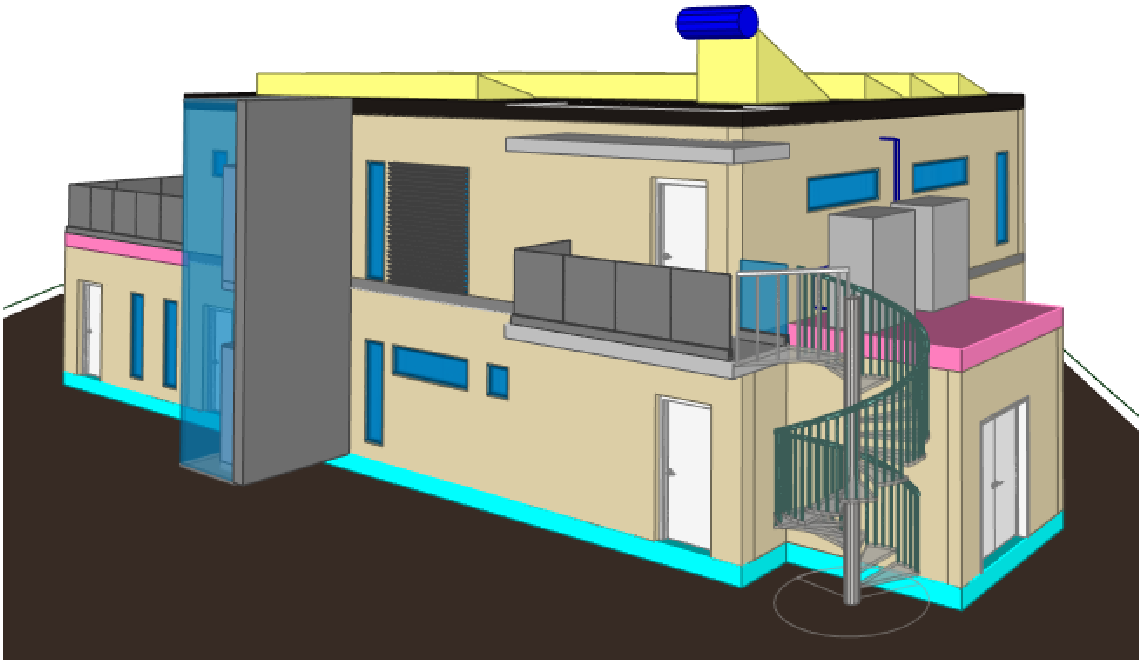


Figure 6: North - East View of Smart House building

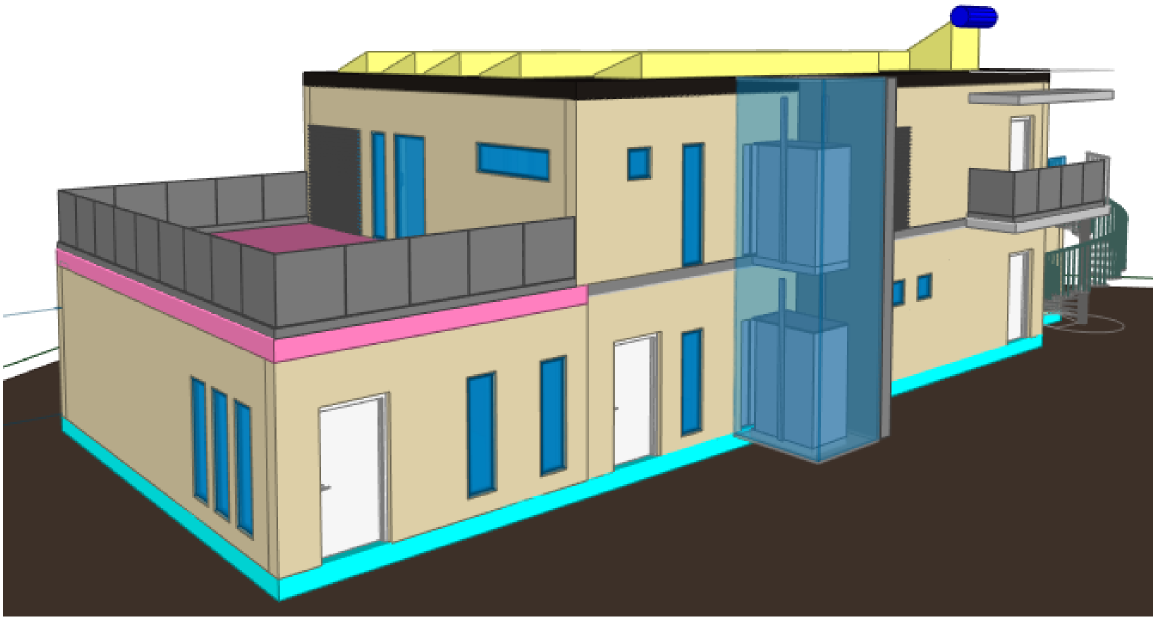


Figure 7: North - West view of Smart House building

Figure 8: Section view of Smart House building

4.3 Building Envelope

The design and construction of the building envelope have taken into consideration all the aspects that ensure safe and energy-efficient construction. The utilized insulation materials have all the necessary specifications to ensure thermal insulation, sound insulation, fire protection, passive ventilation and mechanical endurance. In the following paragraphs, there will be given a thorough presentation of the insulation techniques that have been implemented throughout the Smart House's envelope to achieve the target of near-Zero Energy Building, with an average value of thermal transmittance coefficient equal to 0.578 W/m^{2}K. Additionally, the selection of the glazing and frames for the openings will be presented.

4.3.1 Vertical Walls

The total area of the envelope's vertical elements (walls) in contact with the ambient air is 390.68 m^2. All the brick walls are insulated with 16cm of mineral wool that offers thermal, water, and sound insulation as well as soundproofing. The used material has a thermal conductivity value equal to 0.033 (W/(m·K)). The resulting thermal transmittance is 0.215 W/(m^{2}K). The insulation layer is placed externally. Furthermore, the interior walls were also insulated using a similar mineral-wool insulation product with 0.0352 (W/(m·K)).

The structural elements (columns and beams), have an additional insulation layer under the mineral wool. For this purpose, 10 cm of XPS has been installed to lower the thermal transmittance to 0.13 $W/(m^2K)$. Furthermore, the wall in contact with the machine room of 11 m^2 area, is also insulated in the same way as described above. The machine room's external walls are insulated with 10 cm of mineral wool, externally, and their thermal transmittance is equal to 0.3 $W/(m^2K)$.

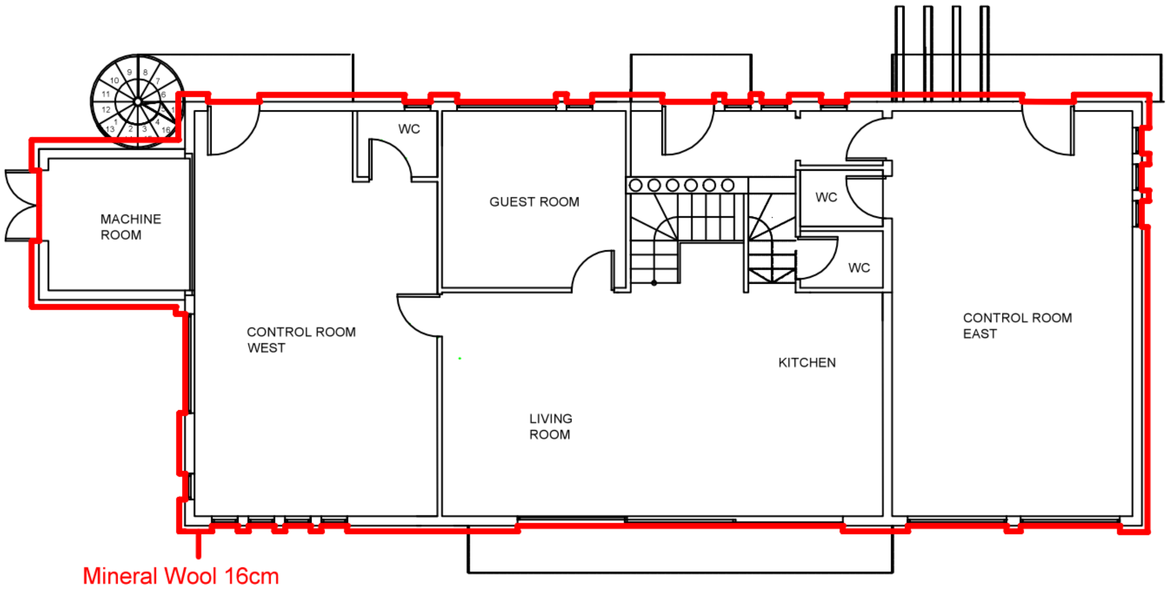


Figure 9: Insulation of vertical building elements - Ground floor plan

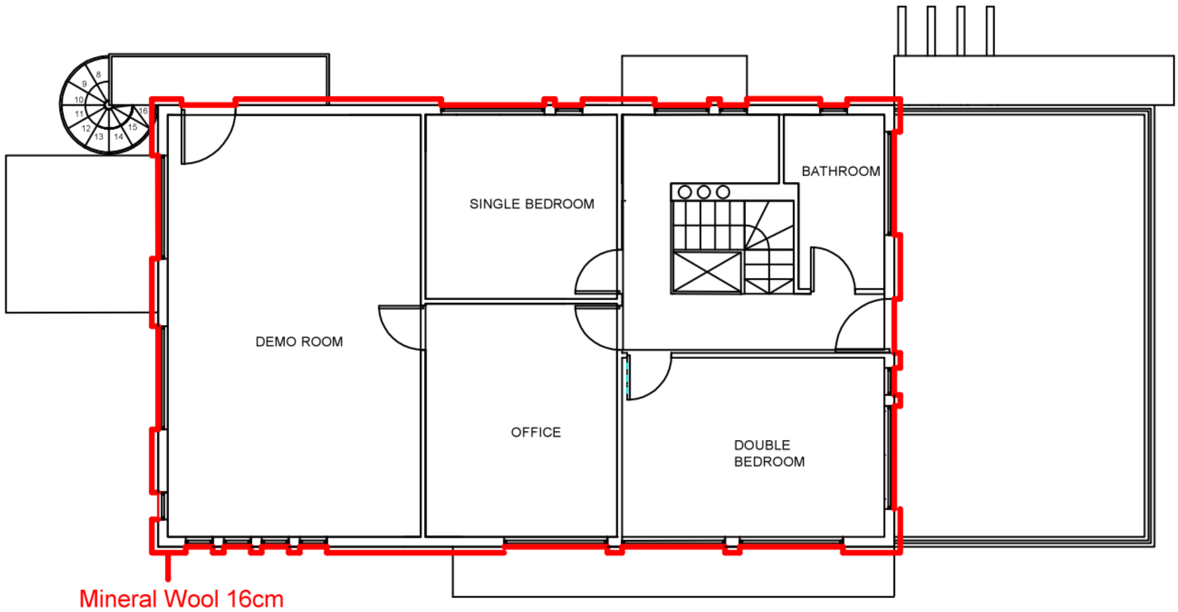


Figure 10: Insulation of vertical building elements - First floor plan

4.3.2 Roof

The supplementary set of examined elements are the horizontal elements in contact with the ambient air (roofs) and they consist of three separate parts that have a total area of 192.6 m^2. All the slabs are constructed with reinforced concrete (2% reinforcement), whose values of density and thermal conductivity are ρ=2400 (kg/ m^3) and λ= 2.5(W/(m·K)), respectively.

The first element is the ceiling of the machine room, which has an area of 9.92m^2. The utilized insulation material is XPS with λ=0.0345 [W/(m·K)] and with 10 cm thickness, installed on the external side. Furthermore, there is a coating from building cardboard (asphalted) for water protection. The resulting U-value is equal to 0.303 W/(m^2K).

The second part is the ceiling of the main roof of the house with a total area of 134.95 m^2. In this case, the insulation layer is also external, and 10 cm of XPS have been used to minimize the thermal losses. The respective U-value is 0.303 W/(m^2K). Furthermore, there is a coating of building cardboard asphalt waterproofing membrane, for water insulation.

The third roof is the ceiling of the eastern control room with an area of 47.72 m^2. In this case, the internal insulation layer is comprised of 10 cm mineral wool. The thermal transmittance of this building element is 0.337 W/(m^2K). For damp proofing, asphalt bitumen membrane layers have been placed in the lower and upper slabs.

4.3.3 Floor

The remaining outer part of the building that has been examined for its thermal behaviour is the ground floor. The total floor area in contact with the ground is 192.6 m^2, but only 182.7 m^2 is insulated; the floor of the machine room is uninsulated, as it is a non-conditioned space. The protected part of the floor-slab was insulated with 5 cm of XPS, which has a thermal conductivity value equal to 0.033 (W/(m·K)) and anti-seismic properties. The resulted thermal transmittance is 0.554 W/(m^2K). The insulation layer is installed at the external side of the floor (in contact with the ground), to reduce heat transfer to the ground.

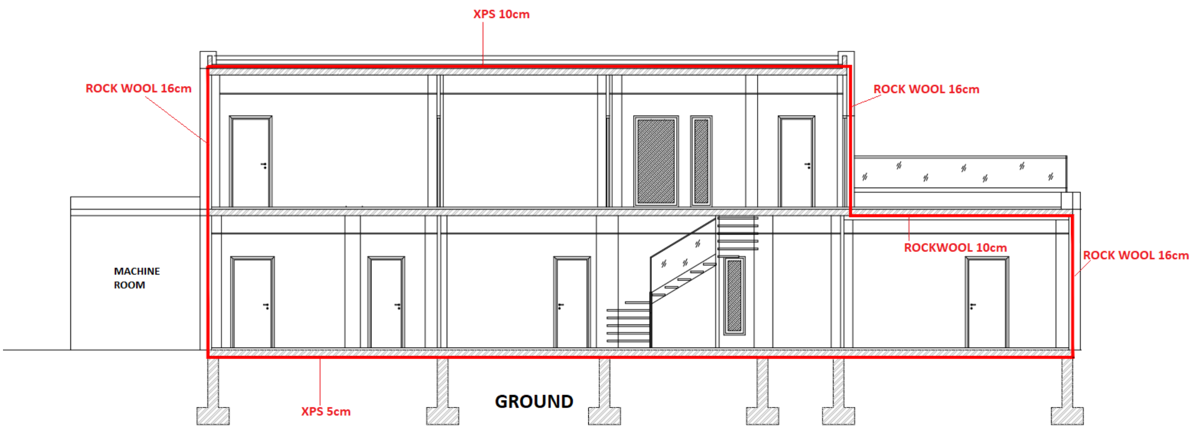


Figure 11: Smart House insulation layout

4.3.4 Fenestration

For the doors and windows of the building, an extra step is needed for the complete description of their properties. In addition to the thermal properties (such as Thermal conductance (U-value), the values of Solar Heat Gain Coefficient (SHGC) and Visual Light Transmittance (VT)) are also presented, which determine the amount of daylight, of solar heat gain and the quality of light entering into the building. Regarding the glazing, two different types were used in this case; double-glazing in the Control Rooms and triple glazing in the “residential” areas of the building. The selected values for the $U_{glazing}$, Light Transmittance and the Solar Heat Gain Coefficient of the double and triple glazing were specified based on the Declaration of Performance (DOP). All the utilized types of window frames (either lifting or sliding) are based on the latest aluminum technologies and they are equipped with thermal break insulation.

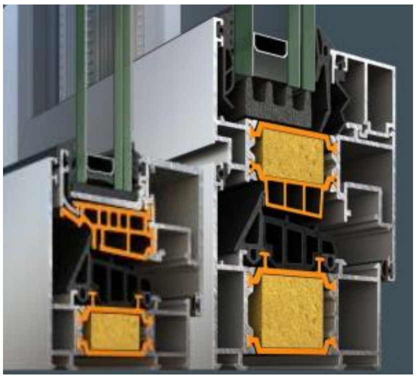


Figure 12: Advanced casements insulated window frame

The detailed values for each opening type (both windows and doors), as installed in the nZEB Smart House, are presented in Table 3.

Table 3: Detailed properties for fenestration and external opaque doors of nZEB Smart House

Opening Type	Glazing	Dimensions (Width*Height) (m × m)	Heat Transfer Coefficient (U_{window}) (W/(m²·K))	Visual Light Transmittance	Solar Heat Gain Coefficient
1	triple	6.9×2.2	1.37	0.74	0.39
2	triple	1.1×2.2	1.38	0.74	0.31
3	double	2.1×2.2	1.41	0.82	0.43
4	triple	2.1×2.2	1.00	0.74	0.4
5	triple	2.1×2.2	1.04	0.74	0.4
6	double	0.55×1.9	1.88	0.82	0.33
7	triple	0.55×1.9	1.64	0.74	0.27
8	triple	0.55×0.55	1.94	0.74	0.19

9	double	2.1×0.55	1.88	0.82	0.33
10	triple	2.1×0.55	1.63	0.74	0.27
11	triple	0.55×2.2	1.63	0.74	0.28
12	Wood panel, metal storm	1.02×2.08	2.3279	0	0
13	Metal	1.4×1.98	3.7021	0	0
14	Wooden	0.78×2.08	2.1944	0	0

4.4 Building Equipment

This section refers to all the electric and mechanical devices or systems that are part of the building. Initially, all the sensors that collect measurements regarding both the indoor and outdoor environmental conditions are presented. The second section is related to the metering of the building's energy consumption (power metering). Finally, there is a thorough analysis of the technical systems that monitor the indoor conditions of the users.

4.4.1 Sensors

The building spaces are equipped with a number of sensors collecting measurements of interest. The whole infrastructure is complemented with the Smart Home IoT Platform, where all data is gathered for real-time monitoring and control and conveniently accessed through a corresponding API. A detailed description of the existing infrastructure is also provided in D3.4 "D^2EPC Platform & Interfaces v2".

Based on the measured values, the existing sensing equipment is categorized as follows.

4.4.1.1 Temperature – Humidity

The indoor temperature and humidity levels throughout the building with a set of sensors, installed in each space. The collection of measurements and storage to the IoT Platform take place periodically every 300 seconds.

4.4.1.2 CO_2

CO_2 sensors are used to measure carbon dioxide levels in each space. The collection of measurements and storage to the IoT Platform take place periodically every 1000 seconds.

4.4.1.3 Luminance

The spaces' light levels are measured using dedicated luminance sensors. The collection of measurements and storage to the IoT Platform take place periodically every 100 seconds.

4.4.1.4 Weather station

A Weather Station metering system, mounted on a building's roof pole, is used to measure outdoor climate conditions, i.e. air temperature, air relative humidity, solar radiation, wind speed and wind direction. Data are retrieved every 10 minutes.

4.4.1.5 Newly-added sensors

Towards effectively implementing the D^2EPC solution to the greatest extent possible, additional sensing equipment was installed within the project, which was proposed within T3.1 as the most suitable for the application and complements the existing infrastructure. To this end, a MCOHome multi-sensor was installed in the building's living room, measuring CO_2, PM2.5 and TVOCs levels, temperature, humidity, luminance, presence, loudness and smoke density. Additionally, an Aeotec Multisensor 6 device was installed in every space of the main building, namely:

- Living room
- Kitchen
- Guest room
- WC
- Hall
- Corridors
- Double bedroom
- Single bedroom
- Bathroom
- Playroom (serving as an office space)

The sensors measure temperature, humidity, luminance, presence, vibration and UV. The integration of the aforementioned sensors allowed CS1 to serve as a testing ground for completely assessing the Human Comfort & Wellbeing performance aspects, as determined within T2.2.

4.4.2 Meters

As the Smart House utilizes mainly electrical energy to cover its demands (there is no use of a gas or oil-fired boiler), the main purpose of metering is related to electricity.

4.4.2.1 Electrical Energy

Electrical energy consumption is measured for the whole building, as well as for each building floor separately. Furthermore, there are distinct measurements for the electrical consumption of the two existing HVAC units. The building's integrated RES (PV installation and Vertical Axis Wind Turbine) are also monitored in terms of energy production. The temporal granularity of the energy data available in the IoT Platform is 15 minutes.

4.4.3 Systems

This section presents the building's main technical systems that are utilized to achieve the desired indoor conditions. The description includes the systems of heating, cooling, air-conditioning (HVAC) and lighting. Furthermore, the building's RES systems for the production of electricity (photovoltaics) and hot water (solar thermal collectors) are presented. Lastly, there is an analysis of the advanced Automation and Control system installation along with a short technical description of the enhanced elevator system, even though its participation in the overall energy consumption is minor.

4.4.3.1 Heating

The HVAC system installed in Smart House is a Variable Refrigerant Flow (VRF) air conditioning system, used for both heating and cooling of the occupied spaces. Two heat pump units are installed in the building, with the first one being responsible for the heating of the ground floor, while the one for the first floor (Table 4). Both units have identical power supply characteristics: 3Φ, 380-415 V, 50 Hz.

Table 4: Heat-pumps' characteristics for heating

Feature	Heat Pump 1	Heat Pump 2
Ph out [kW]	31.5	25.2
Peh out [kW]	6.1	4.74
COPout	5.16	5.32
Maximum Outdoor Temperature [^oC]	18	18
Minimum Outdoor Temperature [^oC]	-25	-25

There are two types of ceiling mounted AC terminal units, 1-Way (Figure 13) and 4-Way (Figure 14) Cassettes, placed at the different spaces of the building, that constitute the "demand side". Most of the models differentiate simply in the cooling and heating capacity values (while the geometry remains unchanged). The total amount of installed terminal units is 14, divided into 8 units on the ground floor and 6 units on the first floor.

Table 5: Types of Terminal Units and technical characteristics

No.	Terminal Unit Type	Nominal Capacity [kW]		Connected to Heat-pump	Room
		Heating	Cooling		
1	4-way cassette	2.5	2.2	HVAC 1:	Guest Room
2	1-way cassette	3.2	2.8		Entrance Hall
3	4-way cassette	6.3	5.6		Living Room
4	4-way cassette	6.3	5.6		Kitchen
5	4-way cassette	3.6	4		Control Room West
6	4-way cassette	3.6	4		Control Room West
7	4-way cassette	5	4.5		Control Room East
8	4-way cassette	5	4.5		Control Room East
9	4-way cassette	2.5	2.2	HVAC 2:	Back Corridor
10	4-way cassette	2.5	2.2		Single Bedroom
11	1-way cassette	3.2	2.8		Demo Room Front
12	4-way cassette	4	3.6		Demo Room Back
13	4-way cassette	4	3.6		Office

14	4-way cassette	6.3	5.6		Double Bedroom

Figure 13: VRV terminal unit, 1-way cassette

Figure 14: VRV terminal unit, 4-way cassette

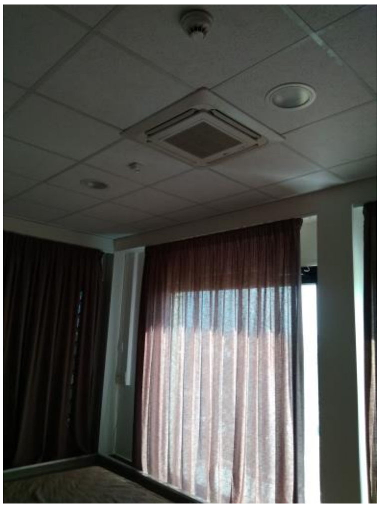


Figure 15: 4-Way Cassette indoor unit placed in Smart House Building

The deployment of the terminal units, the distribution system and the heat production units are presented below (Figure 16, 17).

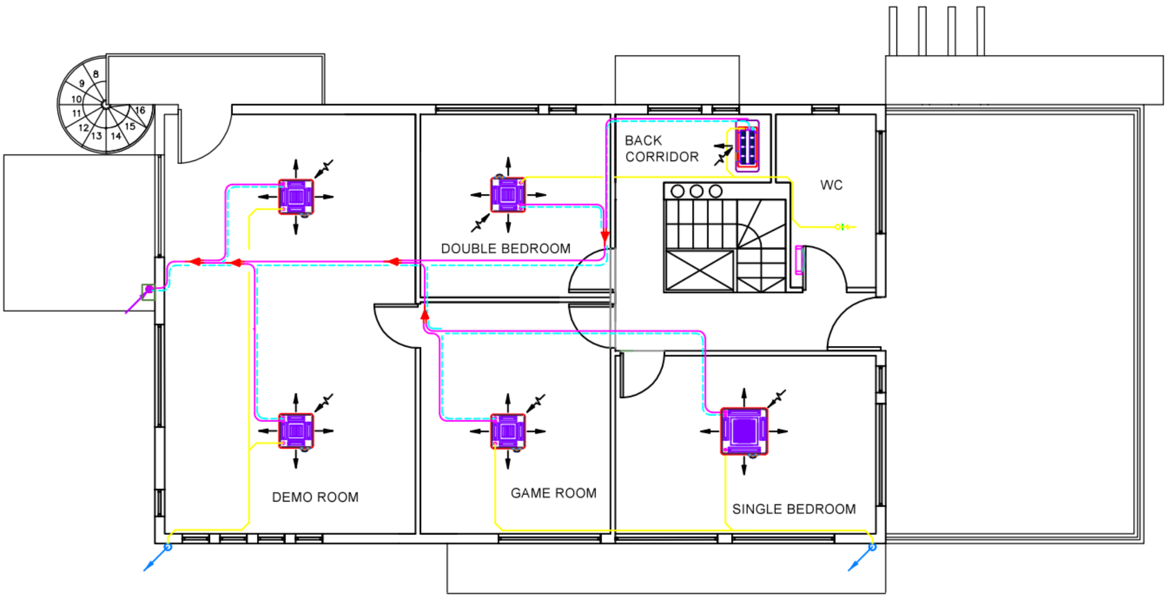


Figure 16: Smart House first floor-plan / HVAC

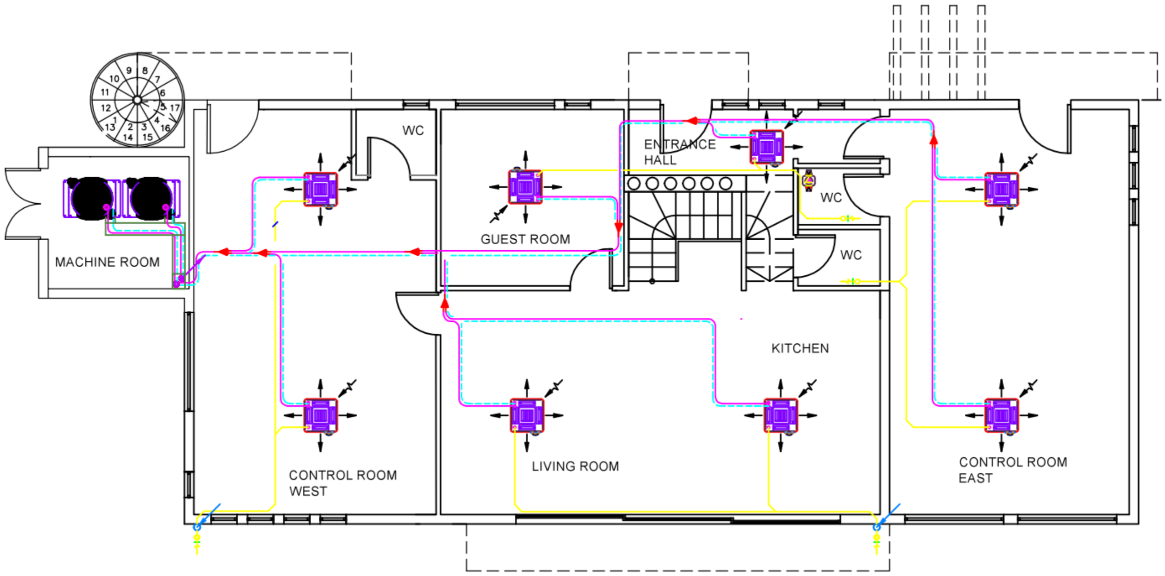


Figure 17: Smart House ground floor-plan / HVAC

4.4.3.2 Cooling

The above-described system (heat-production, distribution, terminal units) is also utilized to cover the cooling demand of the building. Even though the system's components are identical, its behavior and operational characteristics differ in cooling mode, as presented in Table 6.

Table 6: Heat-pumps' characteristics for cooling

Feature	Heat Pump 1	Heat Pump 2
Pc out [kW]	22.4	28.0
Pec out [kW]	4.6	5.98
EERout	4.87	4.68

Maximum Outdoor Temperature (ºC)	43	43
Minimum Outdoor Temperature (ºC)	-10	-10

4.4.3.3 Ventilation

There is no system of mechanical ventilation in the building. The necessary indoor air change is achieved with natural ventilation from the openings.

4.4.3.4 Lighting

The lighting installation differs in the various spaces according to their use. At the spaces that are used as offices, the lighting requirements are more intense. For this reason, 23 lighting panels have been installed in total, on the plenums. Each panel has crosswise parabolic louvres and longwise double parabolic elements. Their shape is rectangular with dimensions 600×600×95mm. Every device includes four LED lamps (fluorine type T8) with a power consumption of 10 W each. At the spaces with residential use (e.g., kitchen, living room, bedrooms, WCs) 43 spot lighting units in total have been installed on the plenums. Each spot is equipped with two LED lamps of 10 W each. The diameter of each spot is 230 mm and has 130 mm height. Furthermore, a linear LED lighting device is placed at the down surface of the upper cabinets of the kitchen, its power is 7 W and its dimensions are 600×250×340mm. At the bedrooms, six wall-mounted scone lights are installed (two in each bedroom) and each device is equipped with a 5 W LED lamp. Lastly, the emergency lighting includes four exit LED 2 W. They are equipped with Ni-Cd batteries that are capable to provide lighting for 2 hours. The total power consumption of the building's lighting system is calculated equal to 1.95 kW (Office spaces: 0.89 kW, Residential spaces: 1.06 kW).

Figure 18: Light fixtures of Smart House

The allocation of the lighting equipment is presented in Figures 19 and 20.

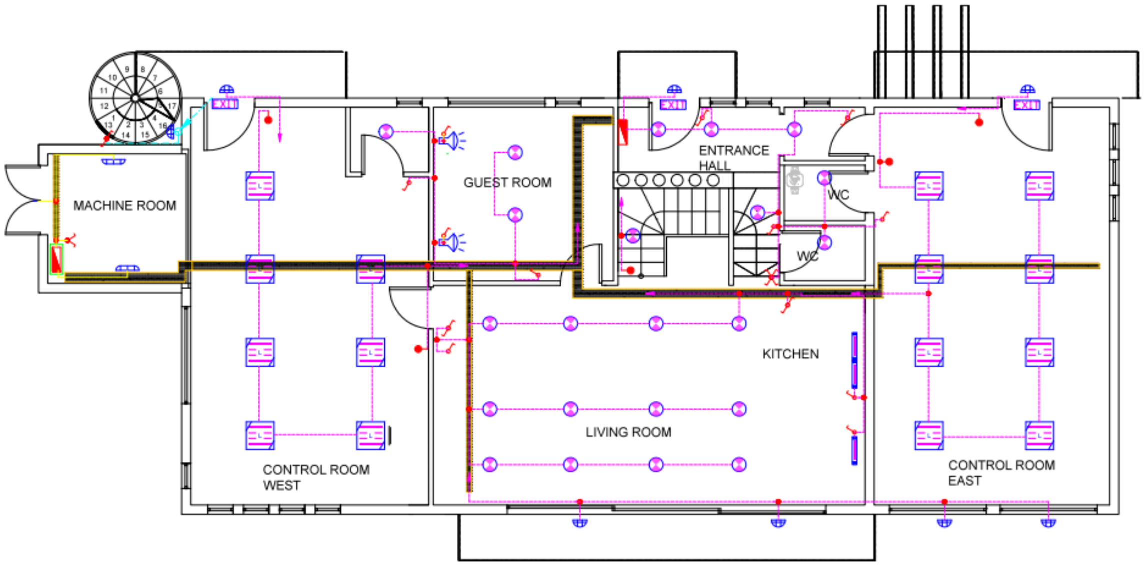


Figure 19: Smart House ground floor-plan / lighting

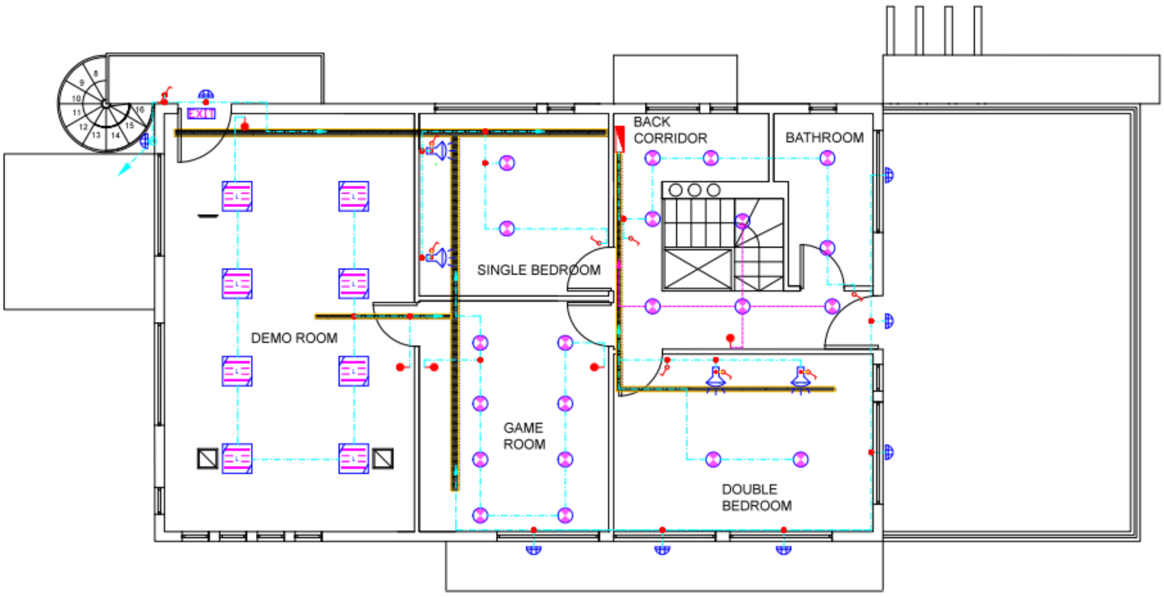


Figure 20: Smart House first floor- plan / lighting

4.4.3.5 Photovoltaic installation

In order to minimize its energy dependence on the external electrical grid, nZEB Smart House is equipped with a building applied photovoltaic (BAPV) roof system for self-consumption. The installed capacity of the PV panels is 9.57 kWp, achieved with 58 panels mounted on the roof with a fixed orientation and slope to maximize energy production. The installed thin-film panels take advantage of the Copper-Indium-Selenium (CIS) technology to achieve a performance level of up to 13.8%. The PV panels are connected to a 3-phase inverter with a nominal power of 10 kW, certified and compliant with standards requirements and features from the utility grid operator.

In order to fully exploit the energy provided from the PV system, nZEB Smart House utilizes an Energy Storage System (ESS). The excess amount of electricity produced during the day is stored in a battery system to be discharged later at periods of low solar irradiance and serve the load demand. The ESS system is comprised of two main components; a battery system that stores the energy and the required inverters for the conversion of the electricity. The existence of the ESS not only minimizes the environmental footprint of the Smart House but also upgrades the power quality of the electrical installation. It also ensures a stable and uninterrupted electric equipment operation, regardless of the state of the utility grid.

The used battery type is lithium iron phosphate battery (LiFePO4), which is currently one of the most popular choices for stationary residence applications, as it offers a relatively high number of life-cycles in comparison with other Li-ion battery technologies. The total capacity of the battery systems is 4.6 kWh. The charging and discharging of the batteries are accomplished with 3 single phase inverters - combi type that have a total power capacity up to 9 kW. Each inverter is combined with a specialized battery controller that prevents the discharging of the batteries below the defined limit.

Figure 21: Smart House South view

4.4.3.6 Solar Thermal collector

The Smart House is equipped with a solar thermal flat plate collector for providing DHW, which is installed on the roof. The total area of the collector is 2.5 m^2 (2.0m × 1.25m). The collector is painted with selective titanium paint. The water heated by the collectors is stored in a 200 L tank. During the days of low solar radiation nZEB Smart House covers its needs for hot water through the air-to-water heat pump installation.

Figure 22: Solar thermal collector with hot water storage tank

4.4.3.7 Vertical Axis Wind Turbine

A Vertical Axis Wind Turbine (VAWT) prototype is installed on the building's rooftop, as shown in Figure 23. The turbine height is approximately 3.9 m and its rotation diameter equal to 2.3m. The three turbine blades has been manufactured using the Sheet Molding Compression (SMC) technology, a compression molding process where the compound for SMC contains recycled carbon fiber material, thus creating light-weight, aesthetical and cost-effective products with improved functionality and durability. The rotor of the turbine includes a 24-pole permanent-magnet synchronous electric generator with a nominal power of 1.75 kVA. Through a power rectifier, it is connected to a commercial inverter with a nominal power of 2 kW. The system is expected to produce around 1000 kWh per year.

Figure 23: VAWT installed at CERTH's Smart House

4.4.3.8 Building (Energy) Management | Automation and Control System

The current IoT infrastructure of the nZEB Smart Home enables the remote control of several building systems under a common Building Management System (BMS) and through different protocols. Residential loads, such as the air-conditioning terminal units can be adjusted regarding the desired temperature and operation mode, while the installed lights can be dimmed according to the user preferences. Control of the in-premises energy storage system is also possible. Upon these functionalities of the BMS, several control strategies and automated routines have been implemented and are constantly being tested in the building.

4.4.3.9 Elevator

The elevator is designed to meet all the necessary European and national standards for modern lifting systems, including the regulations for people with disabilities. It supports numerous new technologies, in the context of integration into the existing Smart Home Monitoring and Control system, with the most typical examples being the energy return via inverters, the use of thermography for the detailed detection of human presence distribution and the interconnection with assisting robotic systems. The additional systems, which facilitate electrical and mechanical lift monitoring, as well as the user interaction features, provide additional services to support predictive maintenance and timely debugging.

4.5 Pre-pilot EPC assessment

Thanks to its innovative building design in collaboration with the use of highly efficient technical systems and RES, the Smart House manages to minimize its energy consumption and at the same time offer excellent indoor conditions. As a result, the Smart House has achieved the highest rating in the EPC evaluation process (A+). The results from the National Asset Rating Methodology are presented below in Table 7 and Figure 23. It is important to mention that the Smart House achieves a total energy consumption 87% lower than the Greek reference building (which is considered Class B).

The certification is aligned with the Greek national standards (KENAK[1]), which are based on the EN ISO 13790. The software that was used for the certification is TEE KENAK, which is developed by the Technical Chamber of Greece. The certification procedure has been conducted by IsZEB.

Table 7: Primary energy per final use (kWh/m2)

Final Use	Reference Building	Actual building
Heating	40.7	26.2
Cooling	70.8	51.3
DHW	11.8	9.5
Lighting	92.1	48.4
Contribution of RES-CHP	0.0	106.9
Total	215.5	28.5
Rating	-	A+

Figure 24: Smart House Energy Class

4.6 Pre-pilot SRI assessment

The nZEB Smart House has also been assessed by the SRI certification scheme according to the final technical study commissioned by DG Energy. Figure 24 presents the scores that it achieves at the various domains and the impact of its operation on the occupants as well as other factors (energy

[1] http://www.kenak.gr/

saving, flexibility etc.). Even though the Smart House's score at the Asset Rating scheme is the highest possible (Class A+), its SRI score is relatively low (49%), which highlights the different aspects studied by the two certification schemes.

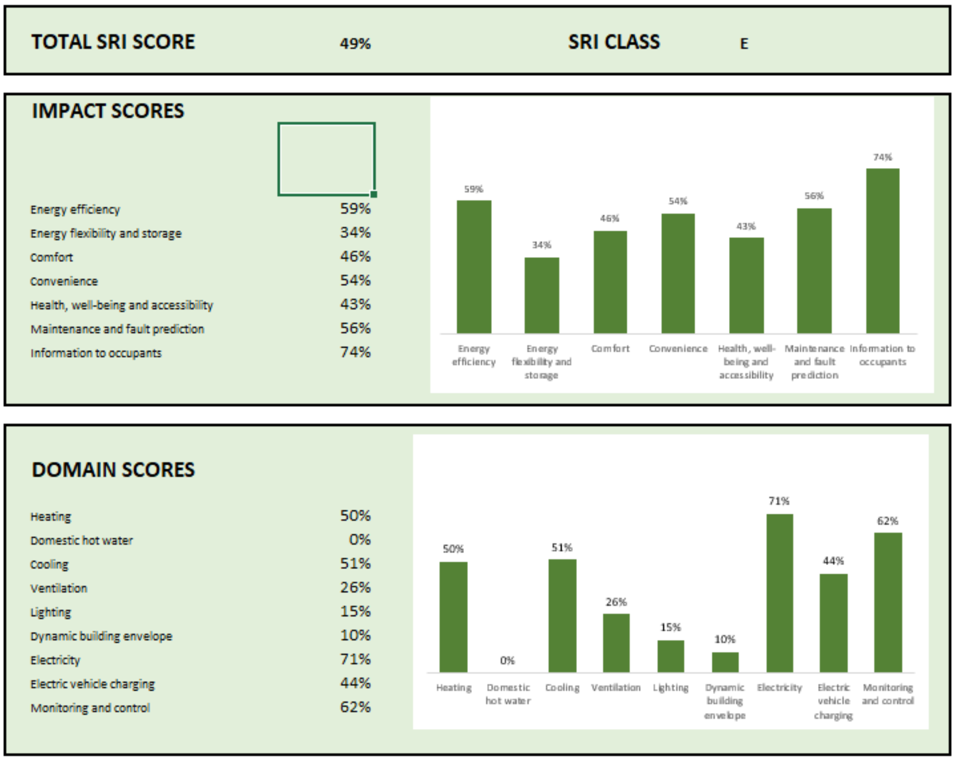


Figure 25: Smart House SRI score

4.7 Scenarios Deployment

As a case study with an advanced monitoring infrastructure that facilitates the testing procedures in a controlled environment, the nZEB Smart Home DIH has been considered as the first testing ground for the entirety of the D^2EPC use cases in different stages of the project's evolvement. Case Study 1 fulfilled the prerequisites for applying the asset-based and operation-based EPC methodologies quite early, in order to provide further implementation guidelines for the rest of the pilots:

- *Complete BIM file delivery*: the building's IFC file was already available by the project's initiation. Within the pilots' preparation period, a number of modifications and extensions were applied to better serve the needs of the project.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: The existing IoT platform facilitated the early collection of measurements from all devices of interest through a software script that resembled the operation of the IML component up to the moment that the latter was deployed in the operational environment. To this end, the delivery of field data was continuous and allowed the extensive testing of the required functionalities.
- *Provision of historical data*: To compensate for any data that were not collected as they preceded the kick-off of the aforementioned activities, historical measurements were retrieved from the existing IoT platform and were utilized to evaluate the as-operated building performance.

Figure 26 displays the digital twin of Case Study 1, combining the BIM literacy with real-time data. More information about the deployment prerequisites can be found in D5.8 "D^2EPC Pilots Demonstration v2".

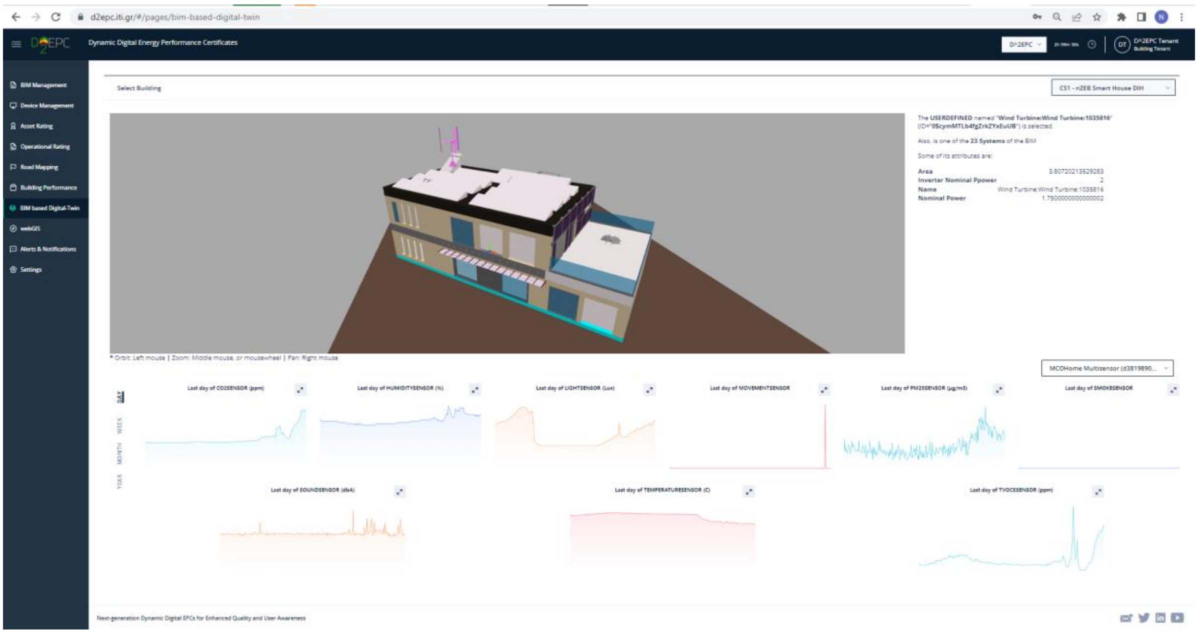


Figure 26: BIM-based Digital Twin of CS1

5 Case Study #2: Residential/Multi-family building in Velten Germany

This pilot building was constructed in 1907 and is located in Velten, which is a city in the northwest of Germany. The building includes apartments used for residential purposes. Currently, the building apartments are occupied by tenants. The living area of this building is 335m^2.

Figure 27: Residential/Multi-family building in Velten Germany

5.1 Objectives and Scope

This pilot is one of the six demonstration sites where the implementation of the concepts and solutions developed by the D^2EPC have been tested and validated. Two apartments have been examined in the scope of this project. The building is equipped with wireless sensors and smart meters that enable the close monitoring of electricity consumption, indoor air quality and environmental conditions. Weather data is currently being collected based on geographical coordinates.

5.2 Topology

The residential house in Velten consists of three floors and a basement, with a total area of 614.4 m^2. The building's plan has a rectangular shape and each floor has the same area. There is only one entrance to the building from the south side. All stories are connected internally by a staircase, with no elevator present.

The pilot building in Velten includes six apartments, two on each floor. The average area per apartment is 50-69 m^2. All technical installations are located in an unheated basement (cellar).

The building is divided into three thermal zones. The first one is the heated residential area, which includes all the flats located on the west, and east sites of the facility. The other two zones include the circulation areas and unoccupied spaces, and they are unheated. The circulation area includes a staircase, which is located in the middle of the south part of the building. The last zone is the unoccupied basement of the building.

Figures 28-31 depict the different floor plans.

Table 8: Zones of pilot building in Velten

Zone	Spaces
Residential	Living room, Kitchen, WCs, Bedrooms, Bathroom, inner circulation areas
Circulation areas	Staircase
Unoccupied	Basement

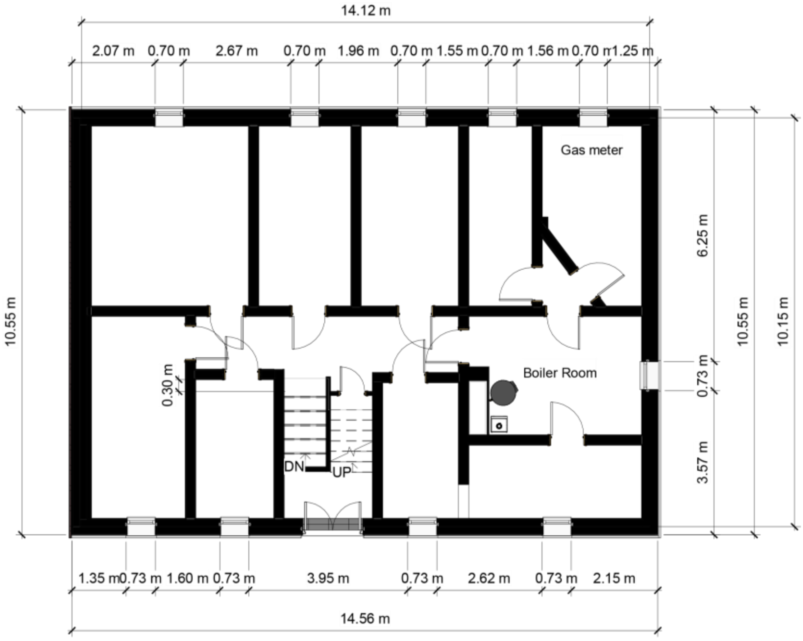


Figure 28: Plan View - Basement

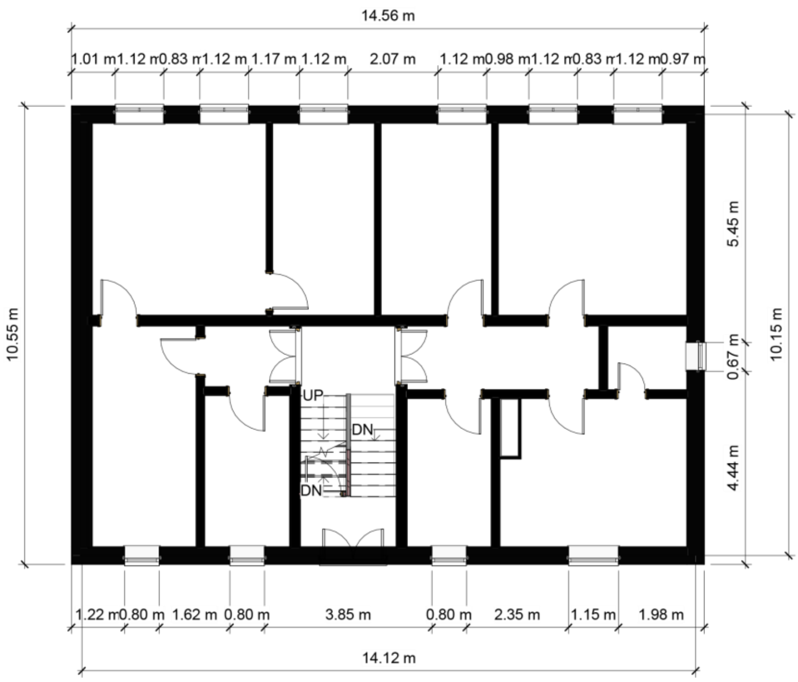


Figure 29: Plan View - 1st Floor

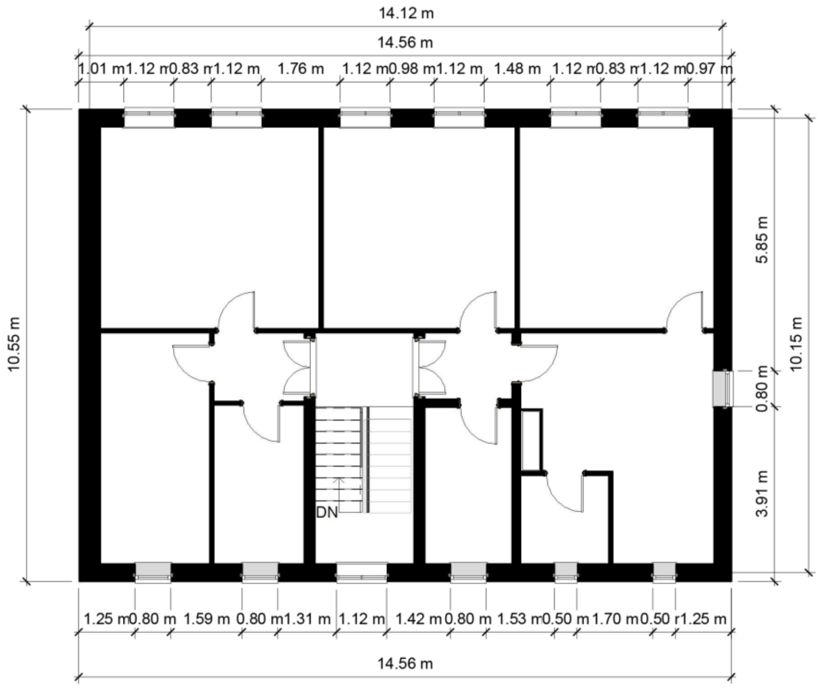


Figure 30: Plan View - 2nd Floor

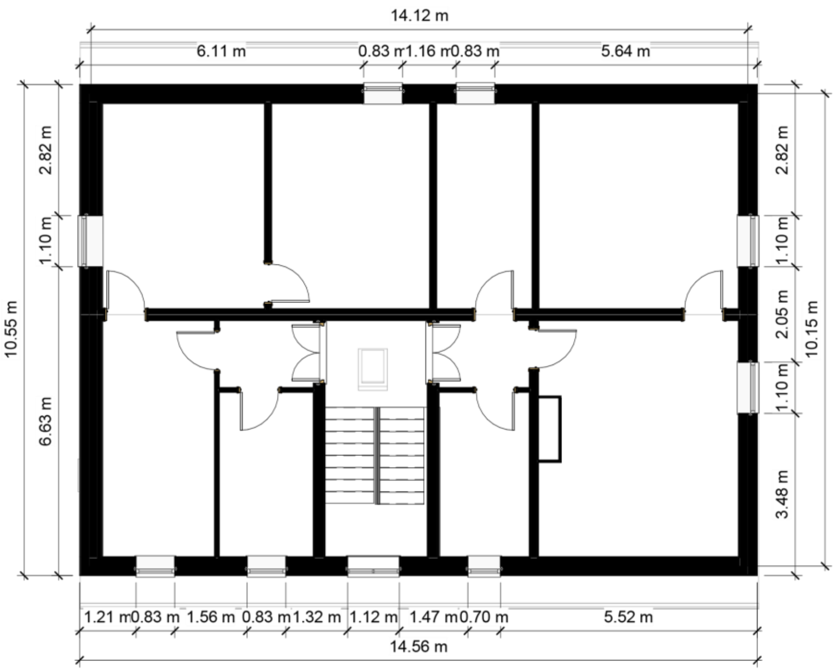


Figure 31: Plan View - 3rd Floor

A photorealistic representation of the building presented in the following figures was created in a BIM environment.

Figure 32: North – East view of pilot building in Velten

Figure 33: South – East view of pilot building in Velten

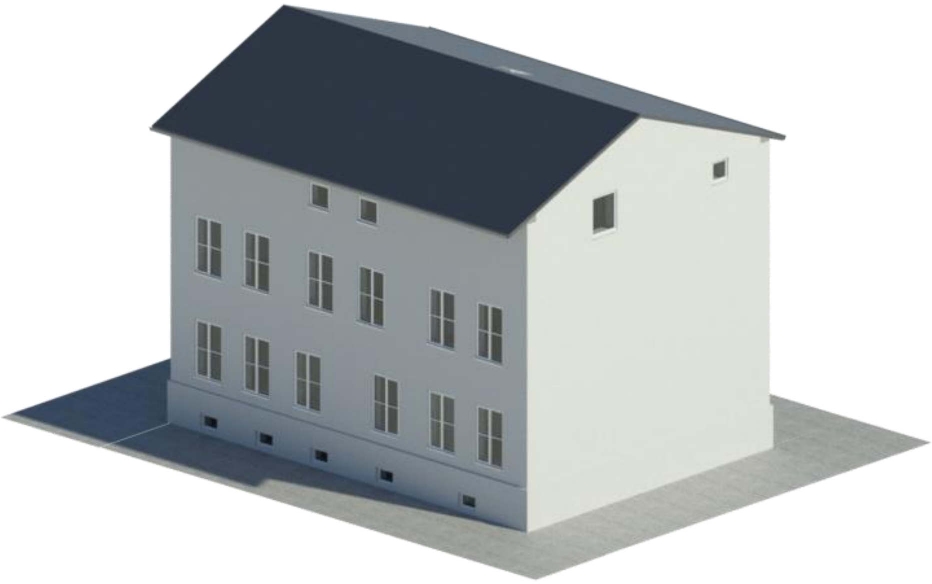


Figure 34: Nord – West view of pilot building in Velten

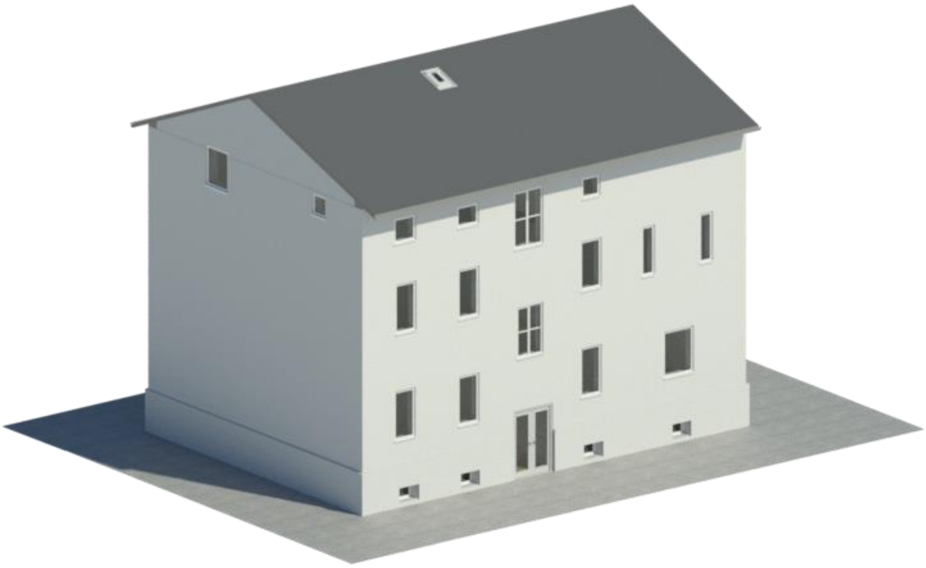


Figure 35: South – West view of pilot building in Velten

5.3 Building Envelope

Due to the fact that the pilot building located in Velten was built in the pre-war period, it is not equipped with modern technologies for effective thermal insulation or intelligent control systems. However, as part of the modernization work, the following renovation activities took place:

- The stove heating system has been replaced with a gas-powered central heating system.
- The decentral DHW production system has been replaced with a central one.
- The western wall of the building has been insulated.
- The old windows have been replaced with new ones.
- A new metal roof was installed on top of the existing old soft roof.

5.3.1 Vertical Walls

The total area of the walls in contact with the ambient air is 510.53m^2. All walls are made of brick, and their width is 40 cm. Only the western wall is insulated with expanded polystyrene (Figures 36-39), as this side of the building needed additional thermal protection. Data derived from the national EPC shows that the western wall's U-value is 0.39 W/(m^{2}K) while the U-value of the other walls is equal to 1.7 W/(m^{2}K).

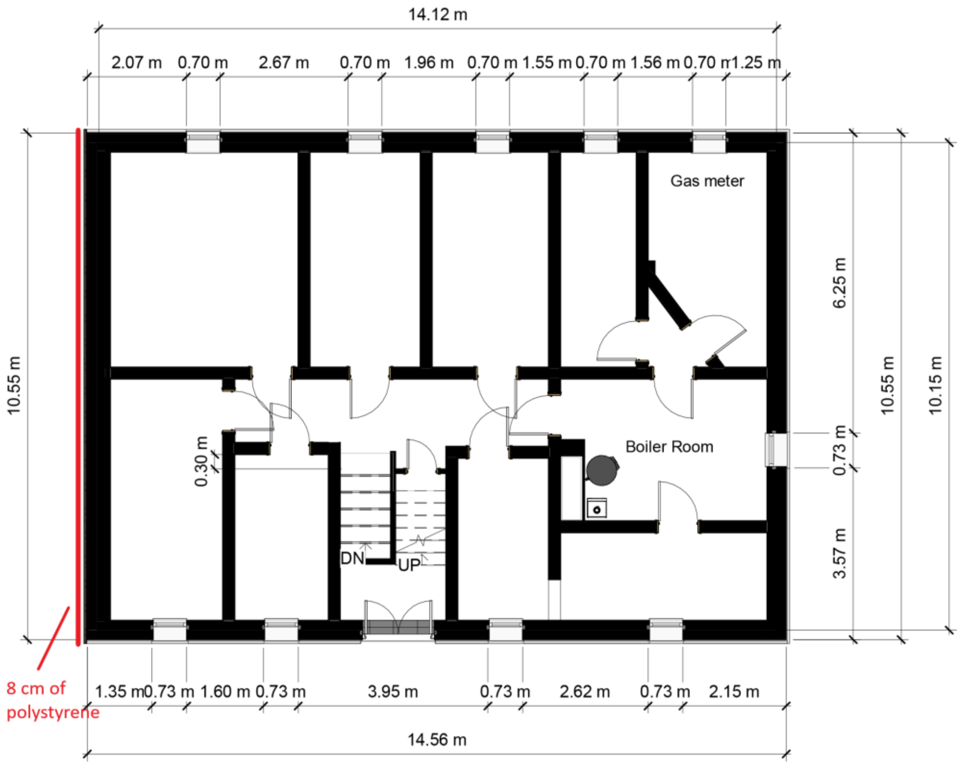


Figure 36: Insulation of vertical building elements – basement

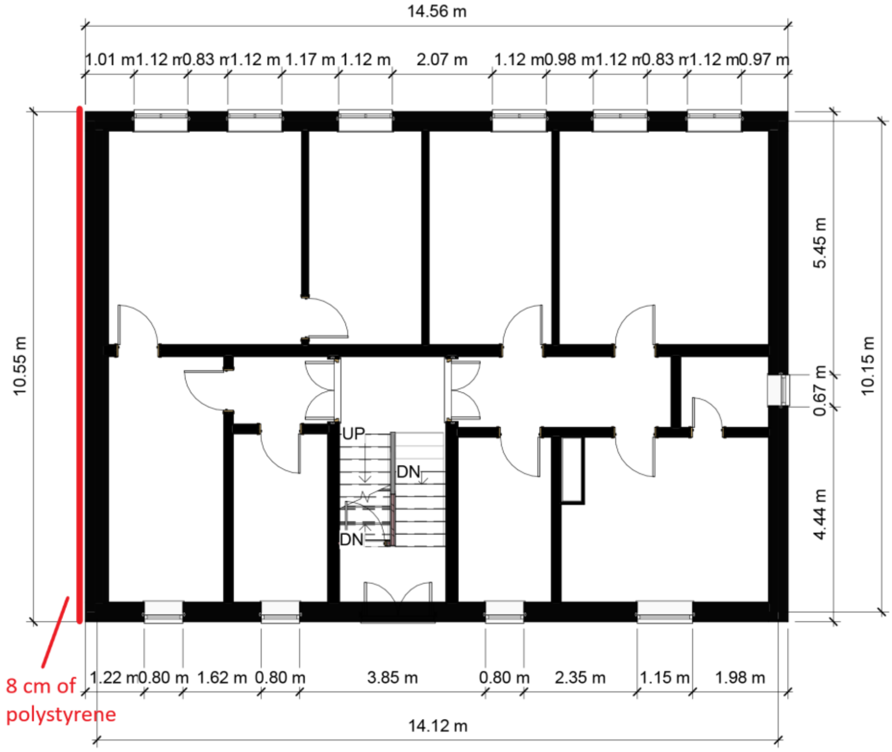


Figure 37: Insulation of vertical building elements – 1st floor

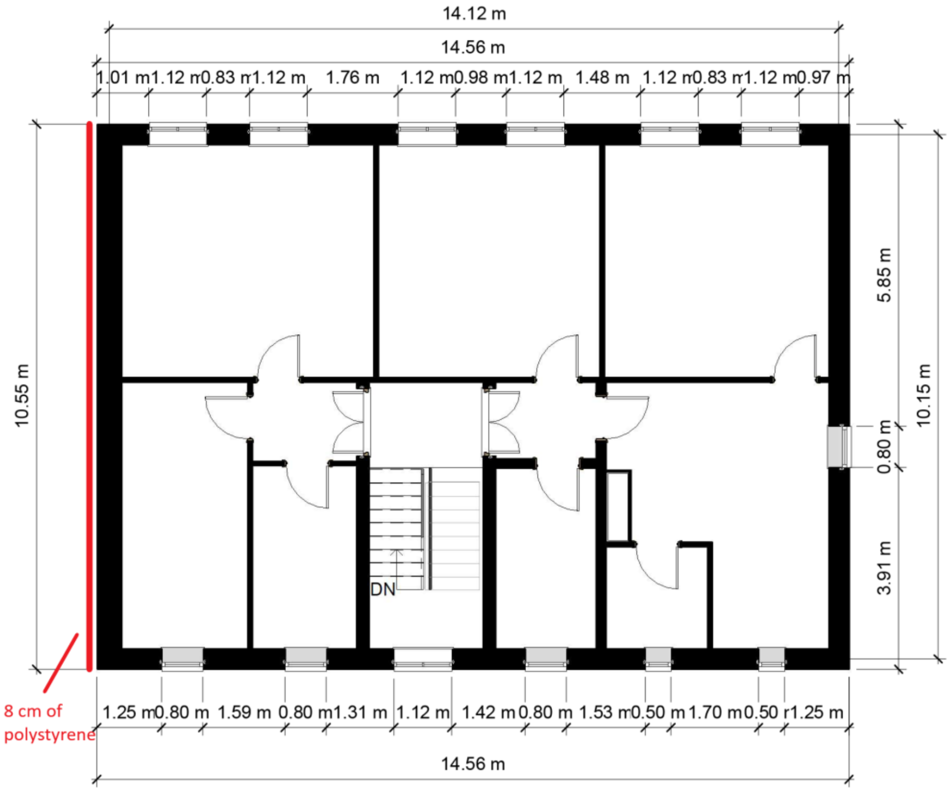


Figure 38: Insulation of vertical building elements – 2nd floor

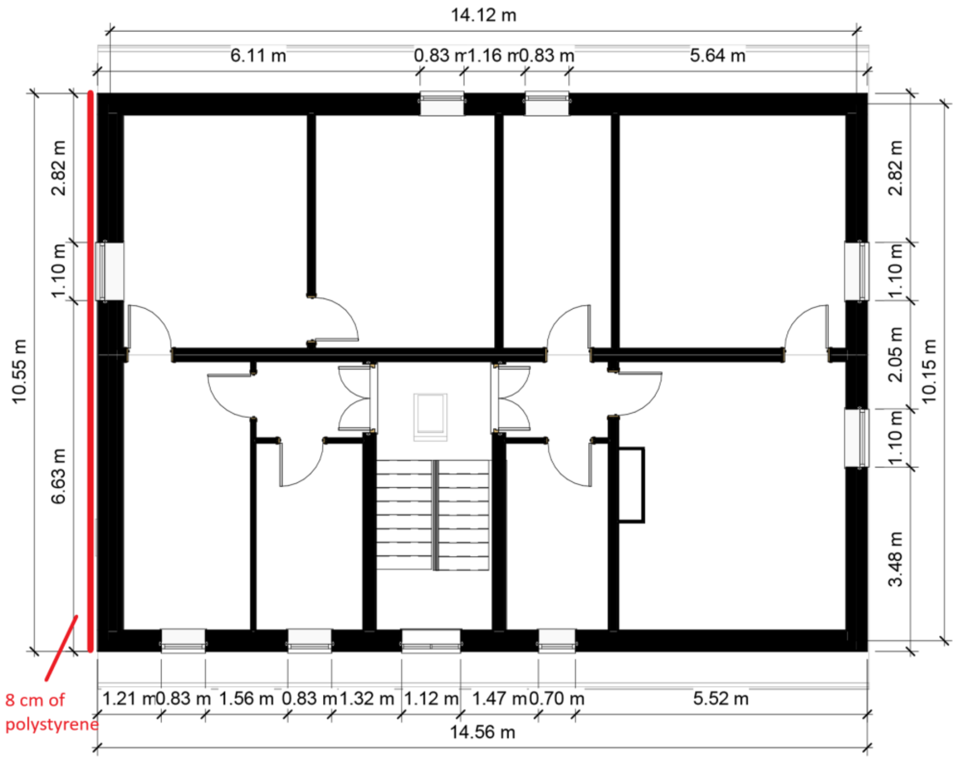


Figure 39: Insulation of vertical building elements – 3rd floor

5.3.2 Roof

The roof was renovated in 2021. As part of the work, a new roof made of metal tiles was laid (Figure 40). However, the previous bitumen covering was not removed, which led to increasing the thermal insulation properties of the roof coating. According to EPC data, the roof's U-value is 0.78 W/(m^{2}K).

Figure 40: Roof Insulation

5.3.3 Windows

In the residential building in Velten there are 44 double glazed windows. In the northern side, there are 19 windows, whereas 18 in the south, 5 in the west one and 2 in the east. The total area of windows is 55.32m^2. Data from the national EPC shows that the window's U-value is 2.7W/(m^{2}K). There is also a skylight in the central part of the building above the staircase. The roof window is also double-glazed, with a U-value of 2.7W/(m^{2}K).

Figure 42: View on south side windows

Figure 41: View on south side windows

5.4 Building Equipment

In this section, a detailed description of the equipment available in the building is presented, including location, type of connectivity for data transfer to the D^2EPC platform and reporting intervals.

5.4.1 Sensors

The building is equipped with temperature, humidity, and CO_2 sensors deployed inside the apartments and the stairways of the building. The building is further equipped with electricity monitoring meters installed in the basement. The existing sensors communicate wirelessly through the Sigfox network, whereas the smart meters use NB-IoT technology. The information collected through the sensors is managed by an IoT platform (ThingsBoard) that enables device management, data collection, and visualization.

5.4.1.1 Temperature, Humidity and CO_2

Inside the apartments the devices installed measure temperature in °C, Humidity in % and CO_2 in ppm (parts per million). Two devices per apartment were deployed covering in total two apartments (2nd and 3rd floors). Two additional devices - sensing both temperature and humidity - were deployed in the stairways (also 2nd and 3rd floors). The shaded areas on the floor maps show the location of the apartments, where devices were deployed (Figure 45 and Figure 46). Information regarding the model, measuring parameters and interval as well as the type of connectivity for data transfer to the D^2EPC platform are shown in the following Table 9.

Table 9: IoT devices installed in the Velten building

Device model	Parameters	Measuring interval	Connectivity
Airwits R4.1	Temperature and humidity	30 minutes - adjustable	REST API
Airiwts R4.1	Temperature and humidity	30 minutes - adjustable	REST API
Airwits CO_2 Plus	Temperature, humidity and CO2	30 minutes - adjustable	REST API
Airwits CO_2 Plus	Temperature, humidity and CO2	30 minutes - adjustable	REST API
Airwits CO_2 Plus	Temperature, humidity and CO2	30 minutes - adjustable	REST API
Airwits CO_2 Plus	Temperature, humidity and CO2	30 minutes - adjustable	REST API

5.4.1.2 Weather station

Weather data such as outdoor temperature, humidity, atmospheric pressure and wind speed are collected via a weather service provider. The targeted interval of data collection is 10 minutes.

5.4.2 Meters

The building is equipped with electricity meters and one gas meter to measure its energy demands. This building's main electrical panel, which is a cabinet where all the electricity utility meters are installed, is located in the basement. In this cabinet, two smart meters (DIN rail) have been installed for the 1st and 3rd floors. The meters collect information on a range of parameters including energy consumption in kWh and use NB-IoT technology. The reporting interval of the meters is 5 minutes, which can be adjusted upwards. Further details on the parameters covered by the smart meters are shown in the following Table 10. In the basement is also located the utility gas meter measuring the energy demands for the whole building.

Table 10: Smart meter model information for the devices installed in the Velten building

Device model	Parameters	Measuring interval	Connectivity
Meazon DinRail v4 smart meter	Active power Current Reactive power Voltage Power factor, and Consumed energy in kWh	5 minutes - adjustable	REST API
Meazon DinRail v4 smart meter	Active power Current Reactive power Voltage Power factor, and Consumed energy in kWh	5 minutes - adjustable	REST API

Currently, the information collected by the smart meters is handled by an IoT platform (ThingsBoard), managed by third party operators. Data transfer is expected to be realized in the same manner as for the Sigfox devices, i.e. through a REST API - authentication process required.

Figure 43 shows the electrical, gas and water systems in the basement of the building. The smart meters are depicted with the icons in orange color while the gas meter is marked with the light blue color. Currently, no sub-meter device has been installed to monitor gas consumption.

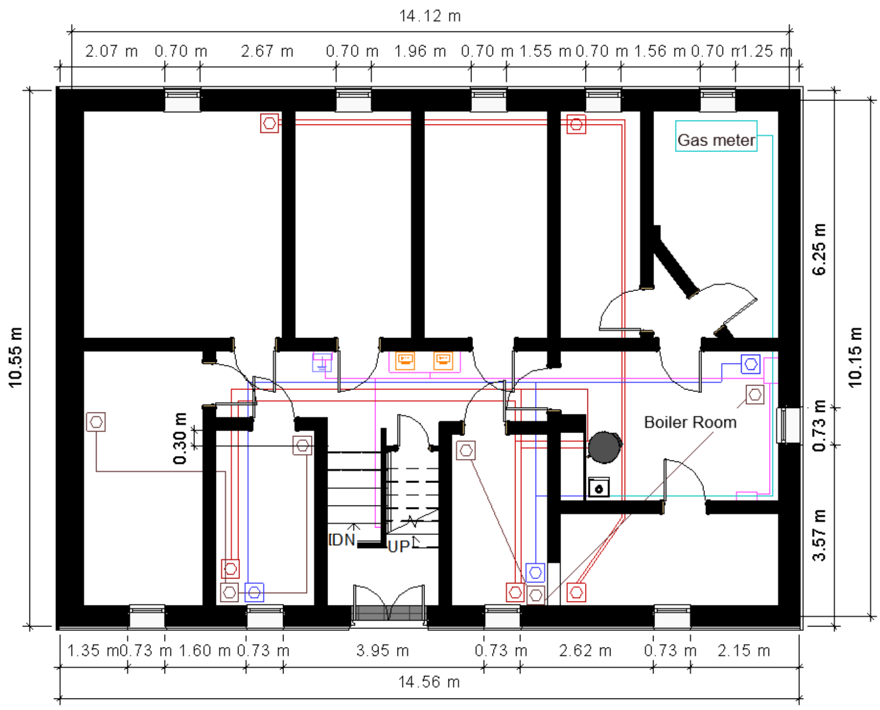


Figure 43: Electrical, gas and water systems - Basement

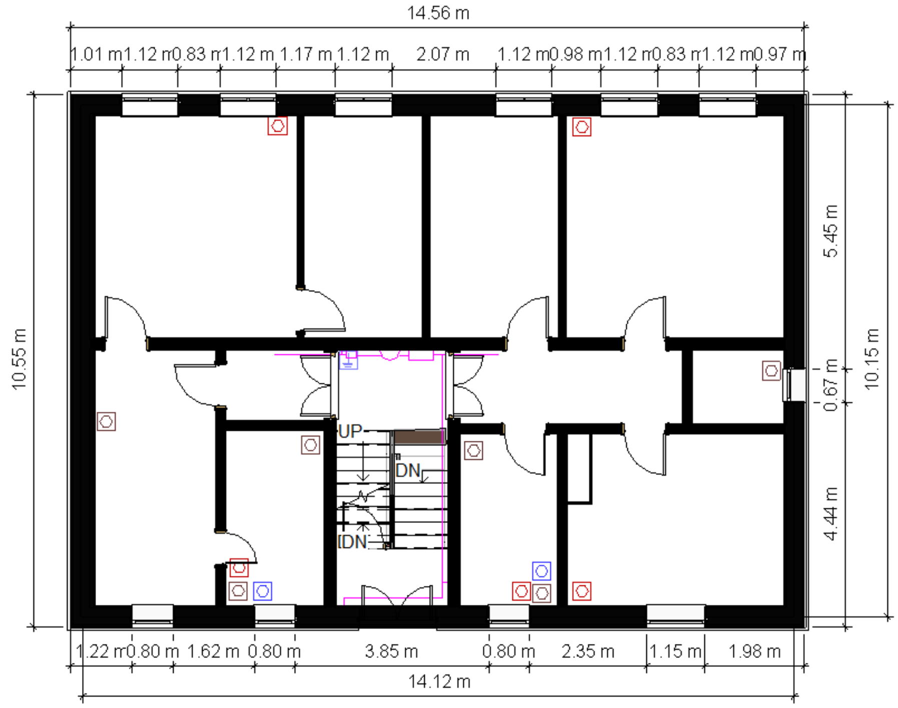


Figure 44: Hot, cold water supply and sewage stack - 1st floor

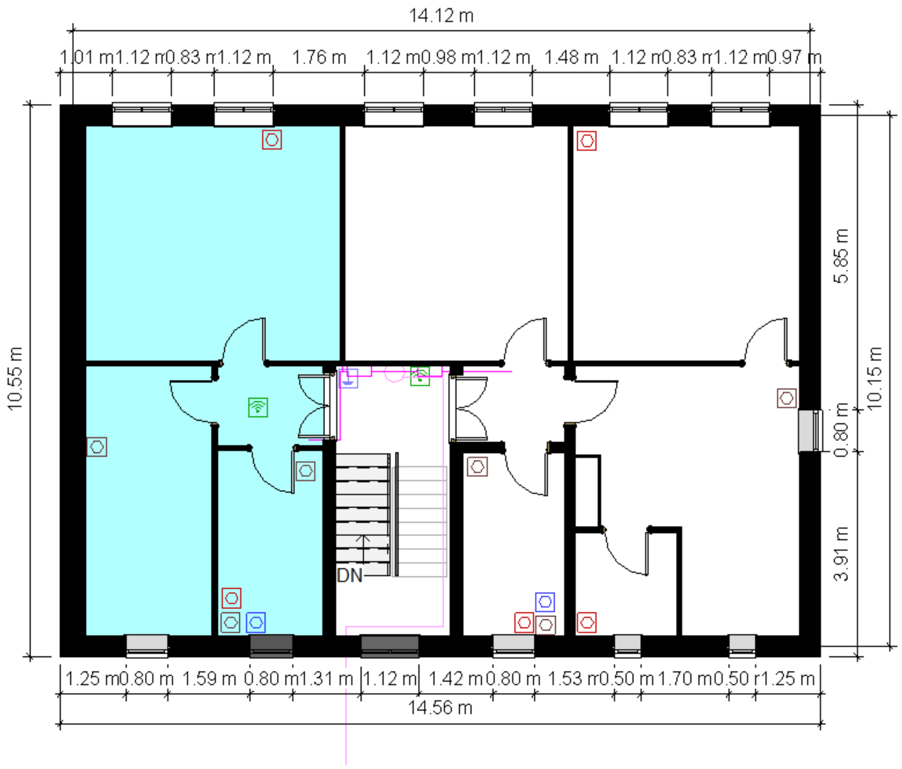


Figure 45: Hot, cold water supply and sewage stack as well as sensors location - 2nd floor

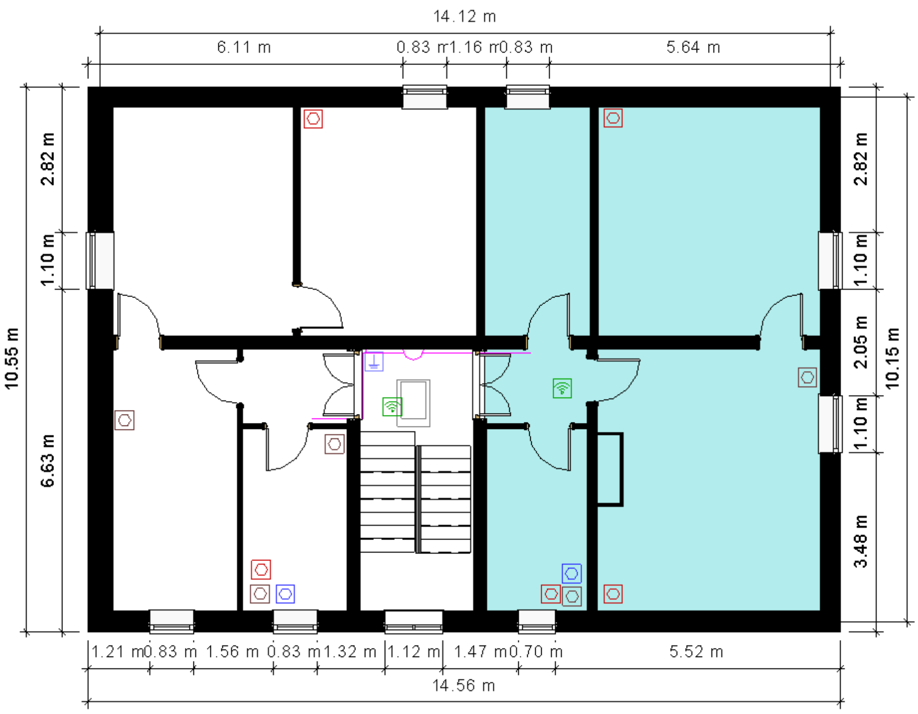


Figure 46: Hot, cold water supply and sewage stack as well as sensors location - 3rd floor

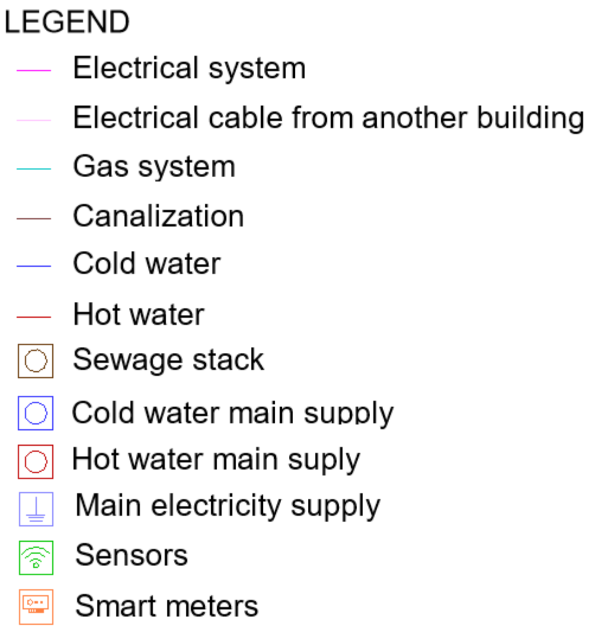


Figure 47: Legend to figures 44-46

5.4.2.1 Electrical Energy

Electrical energy consumption is measured for the circulation areas (one electricity meter), as well as for each apartment separately (six electricity meters). The two pilot apartments have a smart electricity meter installed as described in Section 5.4.2.

5.4.2.2 Water

The water supply system of the building is depicted in Figure 43 as well as the location of the boiler with the respective hot and cold-water main supplies and piping.

5.4.2.3 Gas

The floor map in Figure 43 shows the location of the gas meter, which provides natural gas for heating and DHW purposes to the whole building (i.e. six apartments). The gas meter is located at the basement level.

5.4.3 Office & Home Appliances

The use of this building is for residential purposes and does not include any offices. The apartments are rented to tenants for residential use.

5.4.4 Systems

5.4.4.1 Heating and Domestic Hot Water

Gas heating systems are most commonly used in Germany to heat buildings. The heating system consists of one Viessmann Vitodens 200-W gas condensing boiler and one DHW cylinder, Reflex 48 kW, with a capacity of 304 liters. The equipment was installed in 2023 and is set to maintain a water temperature of 60°C and provide hot water to the apartments through radiators. The heating and Domestic Hot Water (DHW) systems are centrally supplied from the boiler room. The delivery of the heating energy in the apartments is achieved through wall mounted radiators.

5.4.4.2 Cooling

There is no mechanical cooling in this building.

5.4.4.3 Ventilation

Lacking any mechanical ventilation system, the indoor air change is accomplished naturally through the building’s openings, i.e. door and windows.

5.4.4.4 Lighting

In the stairways, the lighting system has been recently upgraded with lighting presence sensors.

5.5 Pre-pilot EPC assessment

According to the Energy Performance Certificate (EPC) (asset-based rating), the energy consumption of the building is 156.5 kWh/m^2. The certification was issued in accordance with the German national legislation (ENEV), which was based on the DIN 18599 series of standards for the assessment of buildings.

Figure 48: EPC assessment, pilot Velten

5.6 Pre-pilot SRI assessment

CS2 pilot SRI score has been assessed using Method B according to the technical study commissioned by DG Energy. Figure 49 and Figure 50 the scores it achieves in the various domains and the impact of its operation on the occupants, as well as other factors (energy saving, flexibility, etc.). The Energy Performance Certificate of the building (Asset rating) is considered satisfactory (156.5 kWh/m^2) whereas the SRI score is considered low (17%).

IMPACT SCORES

Energy efficiency	37.8%
Energy flexibility and storage	4.2%
Comfort	40.4%
Convenience	16.8%
Health, well-being and accessibility	25.0%
Maintenance and fault prediction	14.6%
Information to occupants	14.0%

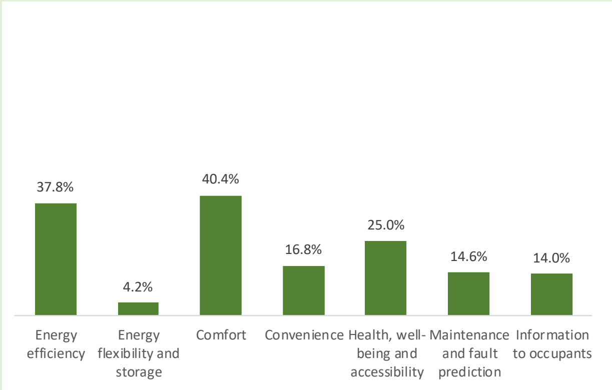


Figure 49: Impact SRI scores, pilot Velten

DOMAIN SCORES

Heating	23.9%
Domestic hot water	28.9%
Cooling	0.0%
Ventilation	0.0%
Lighting	10.3%
Dynamic building envelope	0.0%
Electricity	1.8%
Electric vehicle charging	0.0%
Monitoring and control	16.5%

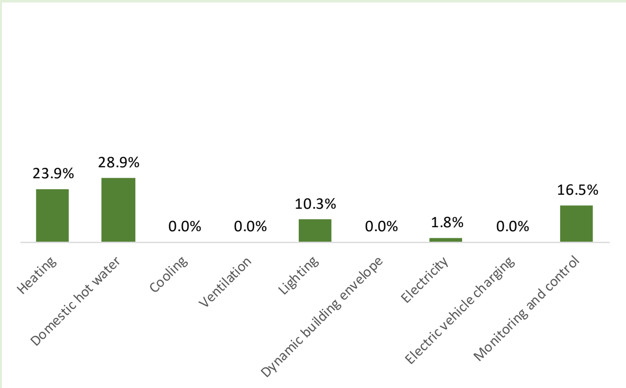


Figure 50: Domain SRI scores, pilot Velten

5.7 Scenarios Deployment

CS2 satisfied the prerequisites for applying the asset-based and operation-based EPC methodologies, as well as to eventually test all the relevant use cases assigned for this pilot in D5.4 – D^2EPC Pilots Demonstration v1:

- *Complete BIM file delivery*: the building's IFC file was provided within the pilot's preparation period. Several modifications were applied, in alignment with the minimum input requirements for issuing the asset-based EPC.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: similarly to CS1, the existing ThingsBoard platform facilitated the data collection by the IML component, allowing the simple definition of the communication interfaces and the resulting continuous data flow after deployment.
- *Provision of historical data*: In cases of not sufficient data for issuing the as-operated EPC, historical data were provided and uploaded manually to the Web Platform

Figure 51 displays the digital twin of CS2, combining the BIM literacy with real-time data. More information about the deployment prerequisites can be found in D5.8 "D^2EPC Pilots Demonstration v2".

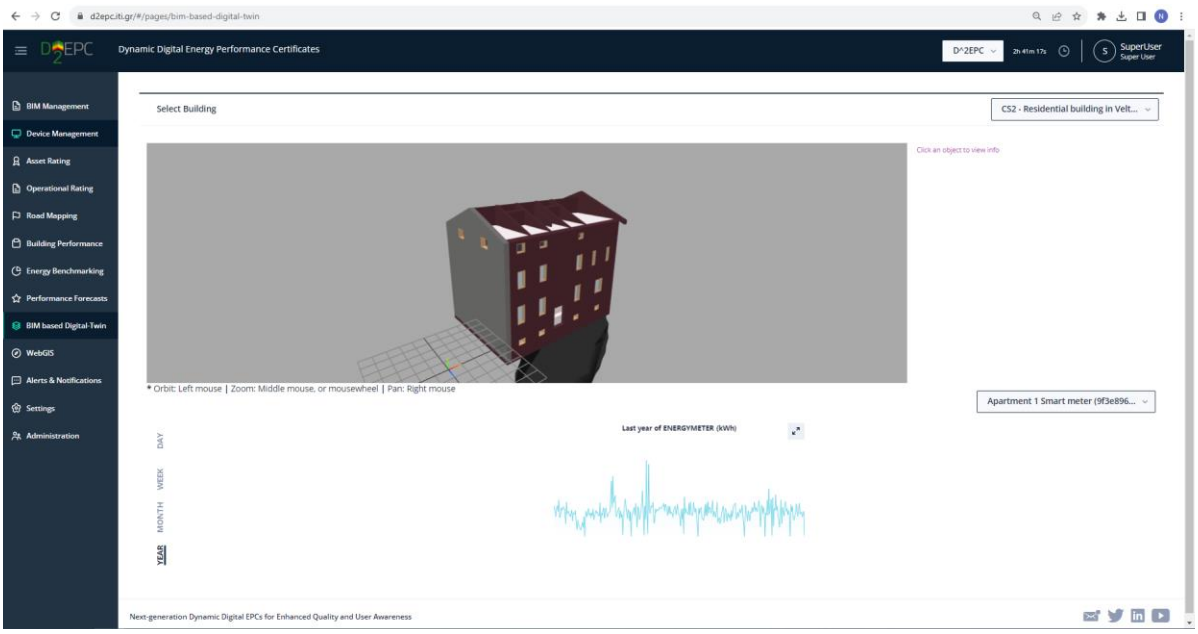


Figure 51 BIM-based Digital Twin of CS2

6 Case Study #3: Tertiary building/Offices in Berlin Germany

Figure 52: Case Study #3: Tertiary building/Offices in Berlin Germany

6.1 Objectives and Scope

The third pilot building corresponds to a metalworking company and has a total area of 2235 m^2. It is located in the city of Berlin, Germany. The building can be divided into the following areas: the stainless-steel production hall 2, which is also hosting a plasma cutting machine, the production hall 1, the staff room, the work equipment warehouse, the lathe and milling shop, the polish and paint shop and four warehouses. The company's offices are located on the first floor, above the work equipment warehouse and turning and milling shops. The other areas are designed as industrial halls. The whole building (excluding offices) is included within the scope of the D^2EPC project.

6.2 Topology

The pilot facility in Berlin is a typical industrial building. The object consists of two floors. On the first floor, there is only an office, the floor area of which is 277 m^2. The rest of the area is occupied by production halls with the necessary infrastructure. The main entrance is located next to a staircase, but each hall also has a large entrance. The building is divided into six thermal zones. Details of each thermal zone are presented in Table 11.

Table 11: Zones of pilot building in Berlin

Zone	Spaces	Conditioned
Hall 1	Production hall 1	√
Hall 2	Production hall 2 and stain steel production	√
Hall 3	Paint shop	√
Hall 4	Lathe and milling shop, two of the warehouses	
Communication	Staircase on ground floor	
Stuff room	Stuff room, one of warehouses	√
Office	Office, staircase on 1st floor	√

The pilot building is connected to other production halls that are not the subject of this project. The location of the pilot is shown in Figure 53.

Figure 53: Case study #3 - Location in relation to other buildings

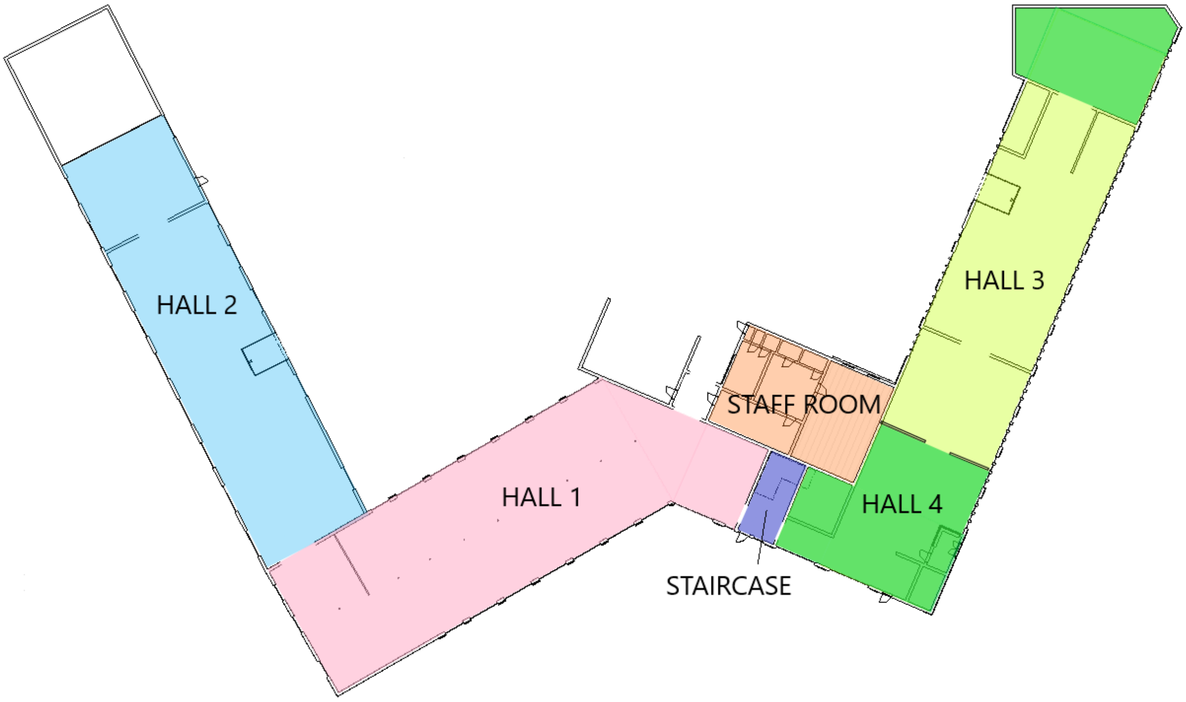


Figure 54: Case study #3 – Ground floor plan of pilot building in Berlin

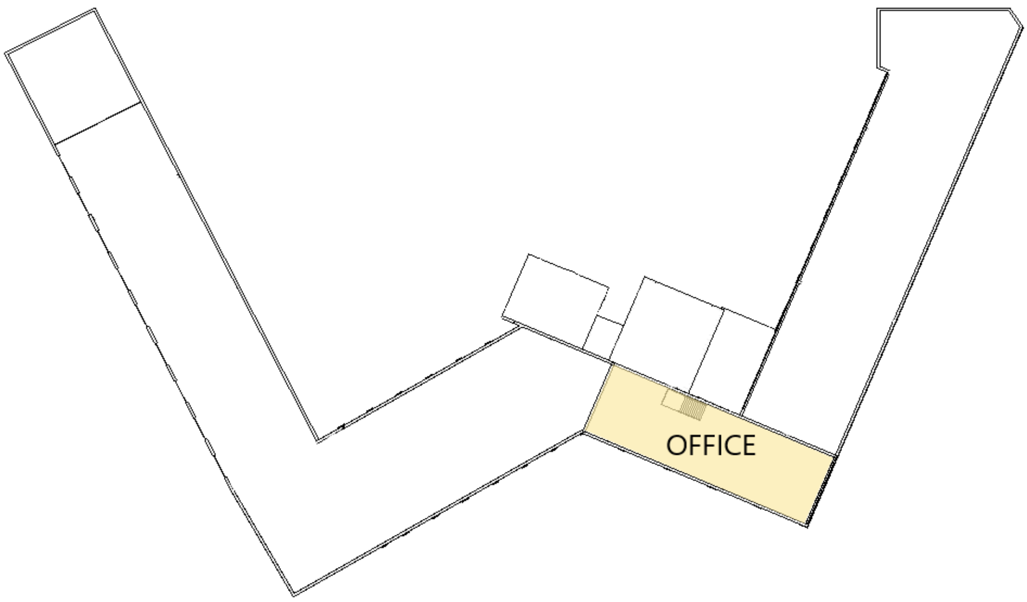


Figure 55: Case study #3 - 1st floor plan of pilot building in Berlin

A photorealistic representation of the building, created in a BIM environment, is presented in the following figures.

Figure 56: Case study #3 – Northeast view of pilot building in Berlin

Figure 57: Case study #3 - Northwest view of pilot building in Berlin

Figure 58: Case study #3 - Southeast view of pilot building in Berlin

6.3 Building Envelope

The presented pilot building is a typical production hall, which lacks the features of respective modern buildings. The overall building's insulation is insufficient. The building's roof was renovated in some parts. Lastly, all windows except, those belonging to the office, are old.

6.3.1 Vertical Walls

The walls of the whole building are made of brick, 30 cm thick. Additionally, hall 1 is covered with plaster. No further insulation is present. The total area of the walls in contact with the ambient air is 1596.99 m^2. A large part of the wall is occupied by windows. Data derived from the national EPC shows that the brick walls' U-value is 2.38 W/(m^2K) and the hall 1 wall's U-value is 1.72 W/(m^2K).

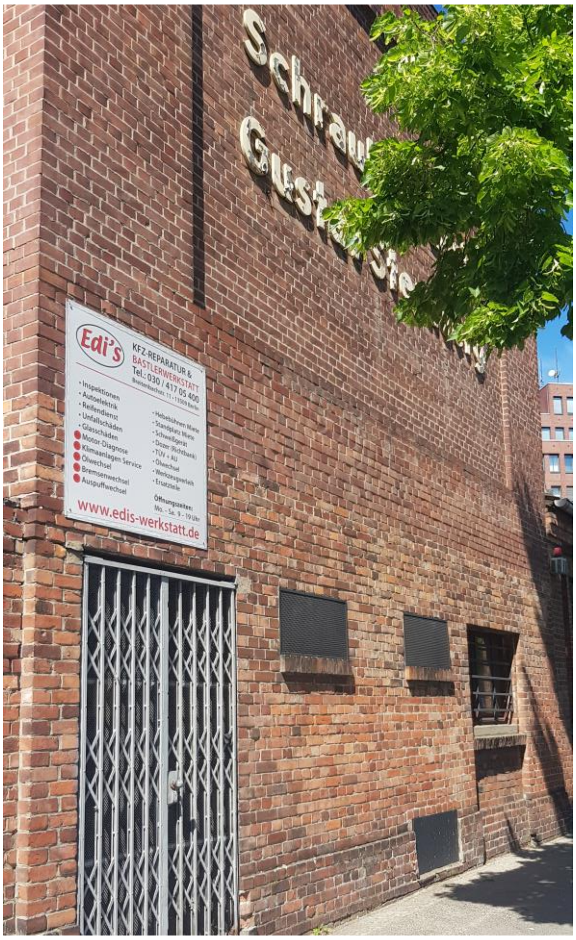


Figure 59: Case Study #3 - View of vertical wall

6.3.2 Roof

Production Hall 1 already has a new, well-insulated roof made of sandwich panels. Hall 2 has an old roof but is internally covered with a polystyrene gypsum board roof. Production Hall 3 still has the old, uninsulated roof structure. All hall roofs are covered with steel tiles. The roof of the office is flat and finished with roofing felt. According to EPC data, the Hall 1 roof U-value is 0.159 W/(m^{2}K), Hall 2 roof U-value is 0.49 W/(m^{2}K), Hall 3 roof U-value is 1.6 W/(m^{2}K) and roof above the office spaces has a U-value equal to 0.57 W/(m^{2}K).

Figure 60: Case Study #3 - View of the roof of production hall 1

6.3.3 Fenestration

The windows on the first floor belong to the office and are double glazed. The rest of the windows on the ground floor have single glazing. The total area of windows is 348.5 m^2. The windows are very large and take up a large part of the walls. According to the EPC data, the double-glazing windows' U-value is 2.7 W/(m^{2}K) and the single-glazing windows' U-value is 5.8 W/(m^{2}K).

6.4 Building Equipment

This building has been equipped with utility electricity, gas, and water meters. Moreover, there are several electrical breaker boxes installed along the production halls for the machines. The production also uses oil for heating purposes. The equipment's location in the building is shown in Figure 61.

6.4.1 Sensors

The devices that sense the indoor temperature, humidity and CO_2 are located at different points in the production halls. The first device is located in Production Hall 1, the second in Production Hall 2, the third in the lathe and milling shop and the last one in the paint shop. The sensors communicate wirelessly using the Sigfox network. The information collected through the sensors is managed by the ThingsBoard platform as in the case of the Velten pilot.

6.4.1.1 Temperature, Humidity and CO_2

Table 12 shows that in total four devices have been deployed in this building. Two devices measure temperature in °C, Humidity in % and CO_2 in ppm (parts per million) and 2 devices measure indoor temperature and humidity. The actual reporting interval of these devices is 30 minutes, which is adjustable from 10 minutes to 24 hours.

Table 12: IoT devices installed in the Berlin pilot

Device model	Parameters	Measuring interval	Connectivity
Airwits R4.1	Temperature and humidity	30 minutes - adjustable	REST API
Airiwits R4.1	Temperature and humidity	30 minutes - adjustable	REST API
Airwits CO_2 R5.2	Temperature, humidity and CO2	30 minutes - adjustable	REST API
Airwits CO_2 R5.2	Temperature, humidity and CO2	30 minutes - adjustable	REST API

6.4.1.2 Weather station

Weather data such as outdoor temperature, humidity, atmospheric pressure and wind speed are collected via a weather service provider. The measuring time interval is 10 minutes.

6.4.2 Meters

The building has a main meter that measures the electrical energy consumption of the whole building, a sub-meter for the large plasma cutting machine and several electrical breakers boxes in the production areas for the various machines. The company has installed three gas meters that measure natural gas consumption for heating purposes. This building also uses heating oil.

6.4.2.1 Electricity, gas, water and oil

The location of the equipment on the floor map of the building is available in Figure 61.

Figure 61: Case Study #3 - Electrical, gas and heating systems as well as sensors location

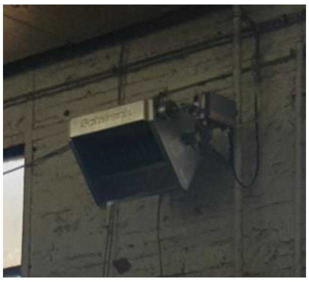
6.4.3 Systems

6.4.3.1 Heating

The building has various types of heating systems depending on the zone. The heating systems for the conditioned zoned are presented in Table 13 .

Table 13: Case Study #3 - Various heating systems

Zone	Type of heating	Picture
Hall 1	Gas heater (200 kW)	

Hall 2	Ceiling radiators (approx. 20 kWth)	
Hall 3	The air heater is powered by oil (203 kWth)	
Staff room and office	Heating system consists of Viessmann Vitodens 200-W condensing boiler and one CVA cylinder Viessmann Vitocell 100-V	 

6.4.3.2 Cooling

There is no mechanical cooling system in this building.

6.4.3.3 Ventilation

There is a ventilation extraction system in the paint shop. The system is operated with two fans with a power consumption of 1.35 kW each, which can be switched independently of one another.

6.4.3.4 Lighting

In Production Hall 1, the lighting consists of LED retrofit. In Production Hall 2, the lighting consists of T5 luminaires in the suspended area and LED Retrofit T8.

6.4.3.5 Domestic Hot Water

A natural gas condensing boiler covers the office and staff rooms' demand for heating and DHW.

Table 14: Domestic Hot Water systems

Equipment	Picture
Viessmann Vitodens 200-W condensing boiler	
CVA cylinder Viessmann Vitocell 100-V	

6.5 Pre-pilot EPC assessment

According to the Energy Performance Certificate (EPC) (asset rating based), the energy consumption average of the building is 506.8 kWh/ m^2. The certification was issued in accordance with the German national legislation (ENEV), which was based on the DIN 18599 series of standards for the assessment of buildings. Figure 62 shows the CO_2 emission value for each part of the building.

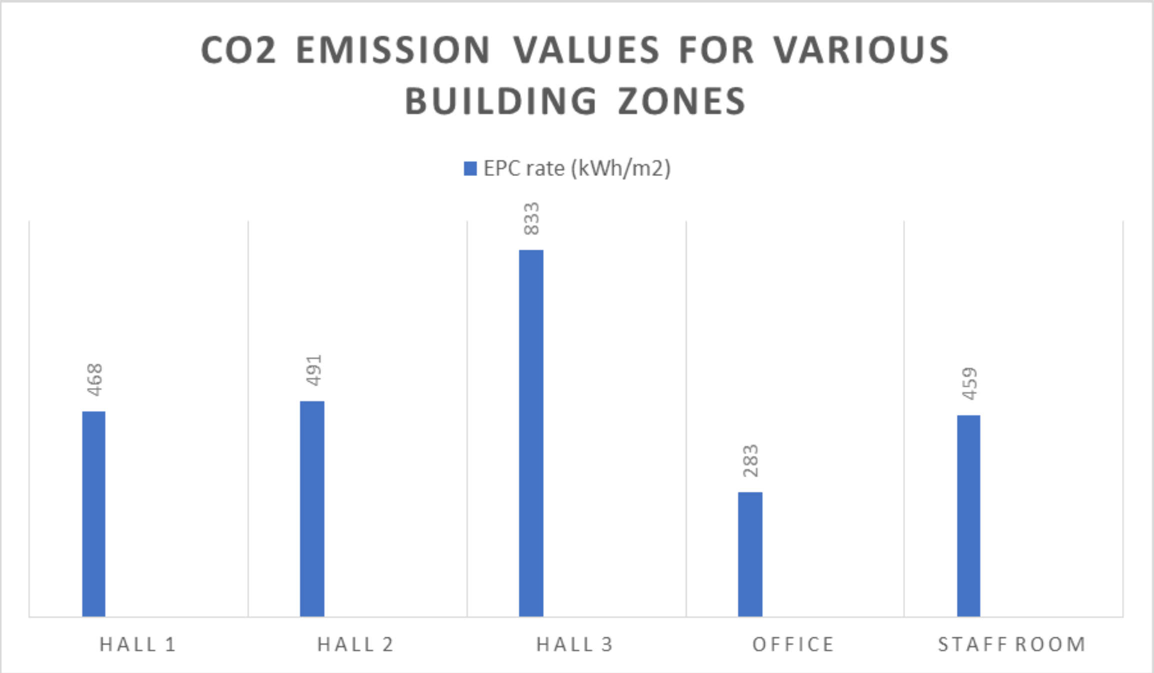


Figure 62: CO_2 Emissions in different areas of the building according to asset rating EPC

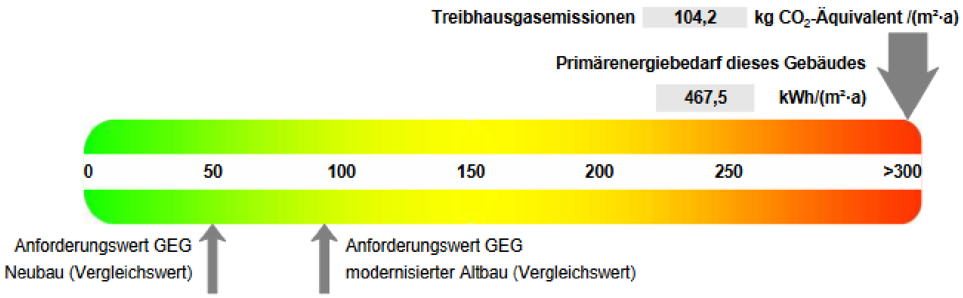


Figure 63: EPC Rating – Production Hall 1

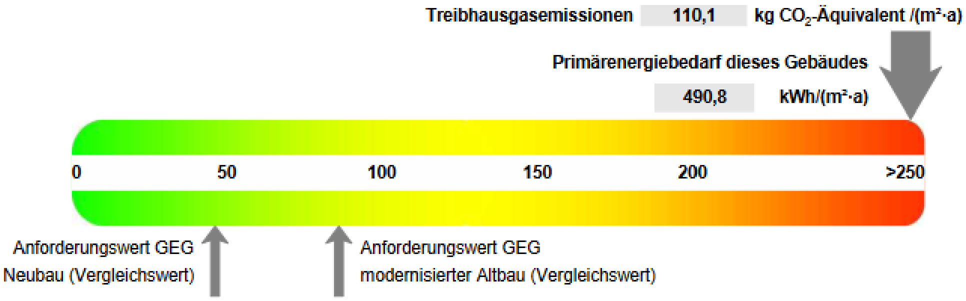


Figure 64: EPC Rating – Production Hall 2

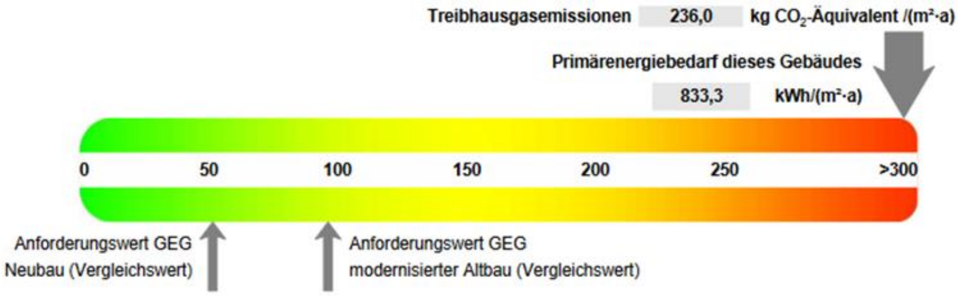


Figure 65: EPC Rating – Paint Shop

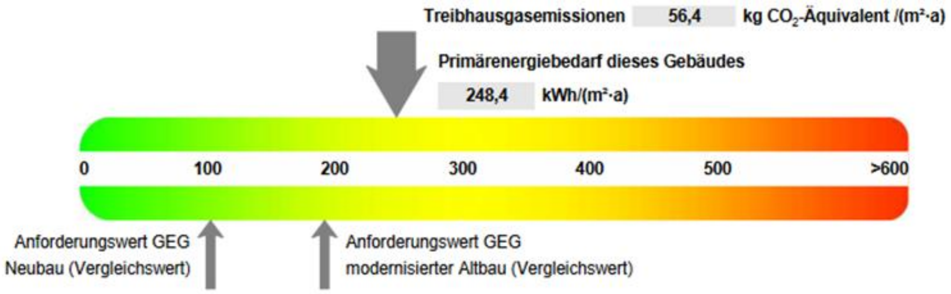


Figure 66: EPC Rating – Office

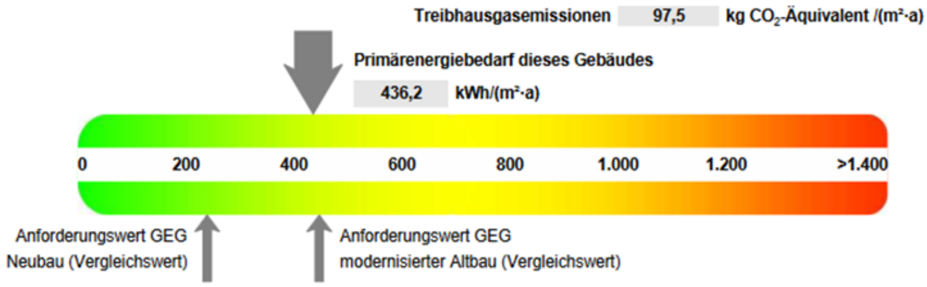


Figure 67: EPC Rating – Staff Room

6.6 Pre-pilot SRI assessment

The SRI score for this pilot has been assessed using the Method B according to the technical study commissioned by DG Energy. Figure 68 and Figure 69 present the scores that it achieves at the various domains and the impact of its operation on the occupants as well as other factors (energy saving, flexibility etc.). The total SRI rating of the building is 6%.

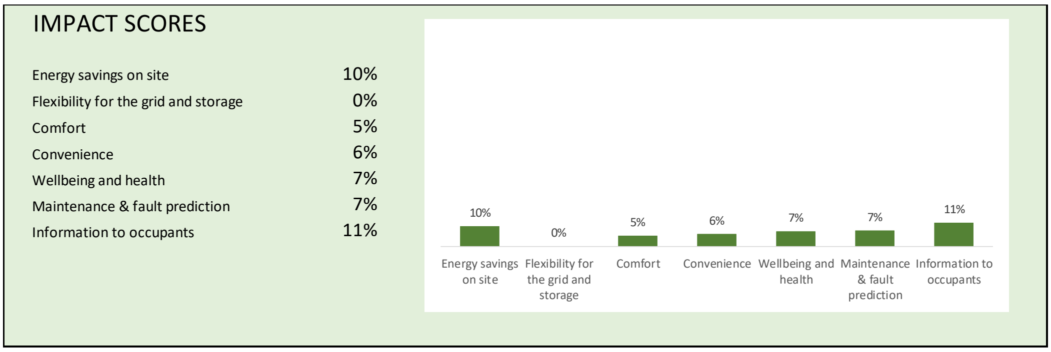


Figure 68: Impact SRI Scores, Tertiary building, offices in Berlin Germany

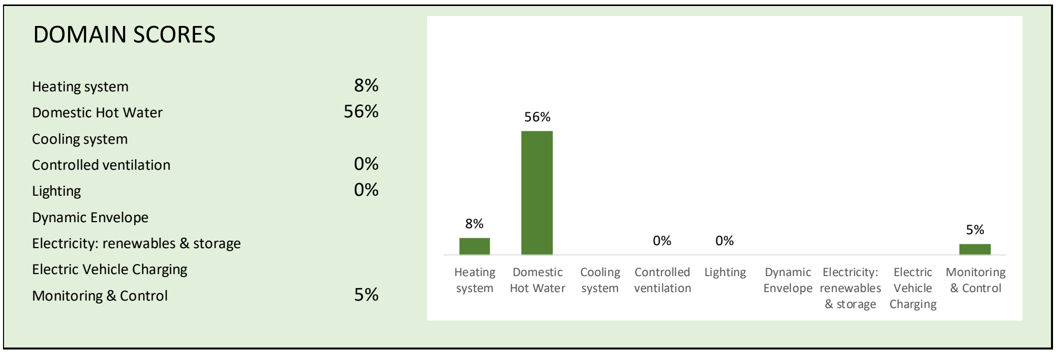


Figure 69: Domain SRI Scores, Tertiary building, offices in Berlin Germany

6.7 Scenarios Deployment

CS3 satisfied the prerequisites for applying the asset-based and operation-based EPC methodologies, as well as to eventually test all the relevant use cases assigned for this pilot in D5.4 – D^2EPC Pilots Demonstration v1:

- *Complete BIM file delivery*: the building's IFC file was provided within the pilot's preparation period. Several modifications were applied, in alignment with the minimum input requirements for issuing the asset-based EPC.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: the existing ThingsBoard platform also facilitated the data collection by the IML component, allowing the simple definition of the communication interfaces and the resulting continuous data flow after deployment.
- *Provision of historical data*: In cases of not sufficient data for issuing the as-operated EPC, historical data were provided and uploaded manually to the Web Platform

Figure 70 displays the digital twin of CS3, combining the BIM literacy with real-time data. More information about the deployment prerequisites can be found in D5.8 "D^2EPC Pilots Demonstration v2".

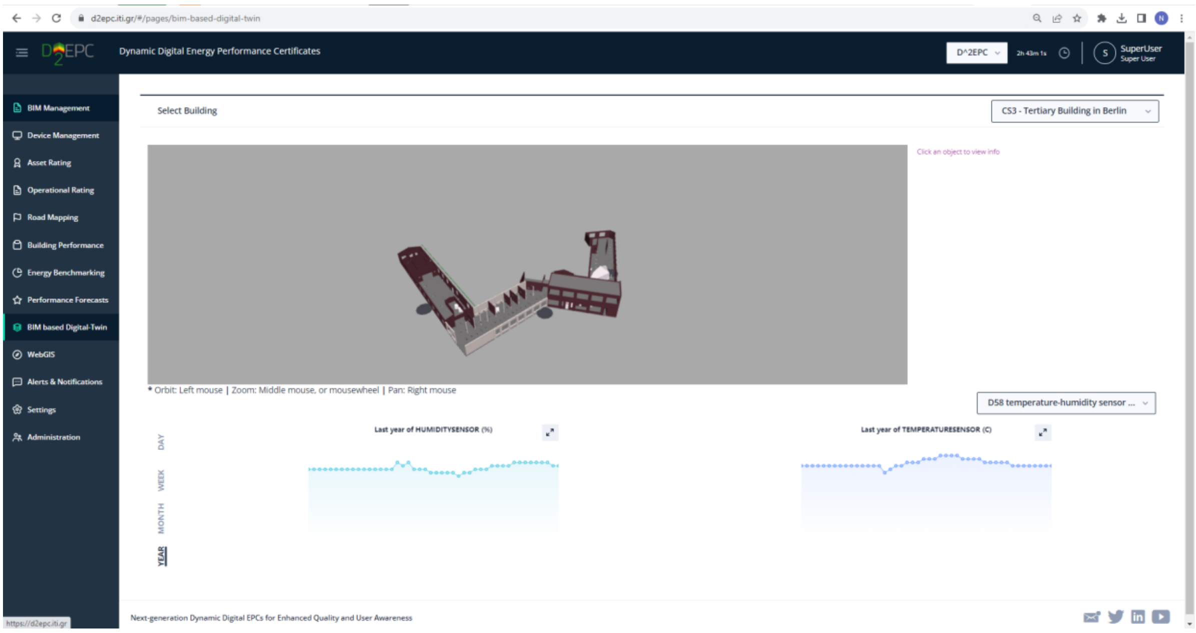


Figure 70 BIM-based Digital Twin of CS3

7 Case Study #4: Mixed-use building in Nicosia Cyprus

The fourth pilot building is located in Nicosia, Cyprus and is owned by Frederick University. The building setup of energy-efficient practical structures and extended smart sensors connections, create the best conditions for testing out the technological advancements that are developed within the D^2EPC project. The amount of data and measurements provided by the installed equipment can be leveraged to gain insight into its operational features.

Figure 71: Frederick University New Wing façade

7.1 Objectives and Scope

The building introduced in this case study is a multi-use building with quite a diverse set of spaces, systems, and assets. The entire new wing building is divided into three separate zones and monitored in detail. The entire building is also covered in terms of energy monitoring, providing a complete data flow that fully depicts the building's status. The building was constructed in 2017 and is operating during the usual office hours of a university as it includes offices as well as seminar halls.

Figure 72: Interior and exterior photos of the Frederick University New Wing

7.2 Topology

The building in Cyprus is located in the area of Palouriotissa, Nicosia, Y. Frederickou Str. (Longitude and Latitude 33°22’46.70 “E, 35°10’46.20 "N), Frederick University's new wing building is a two-story 2100 m^2 building. Its volume is approximately 7100m^3 (including the basement floor/parking area). The understudy building does not border with any other building. The building consists of a basement (area of 450 m^2), ground floor (area of 545 m^2), and two floors (area of 545m^2 on each floor). University's cafeteria is on the ground floor; on the first floor, there are three seminar halls of 220 students’ capacity, and offices are found on the second floor. The building can host up to 390 people. The total height of the building is 15.60 m from the basement floor to the terrace. The individual heights of the floors are 4.10 m for the typical floors and the ground floor. The services that are provided within the building include heating, cooling, ventilation, lighting, and electrical appliances.

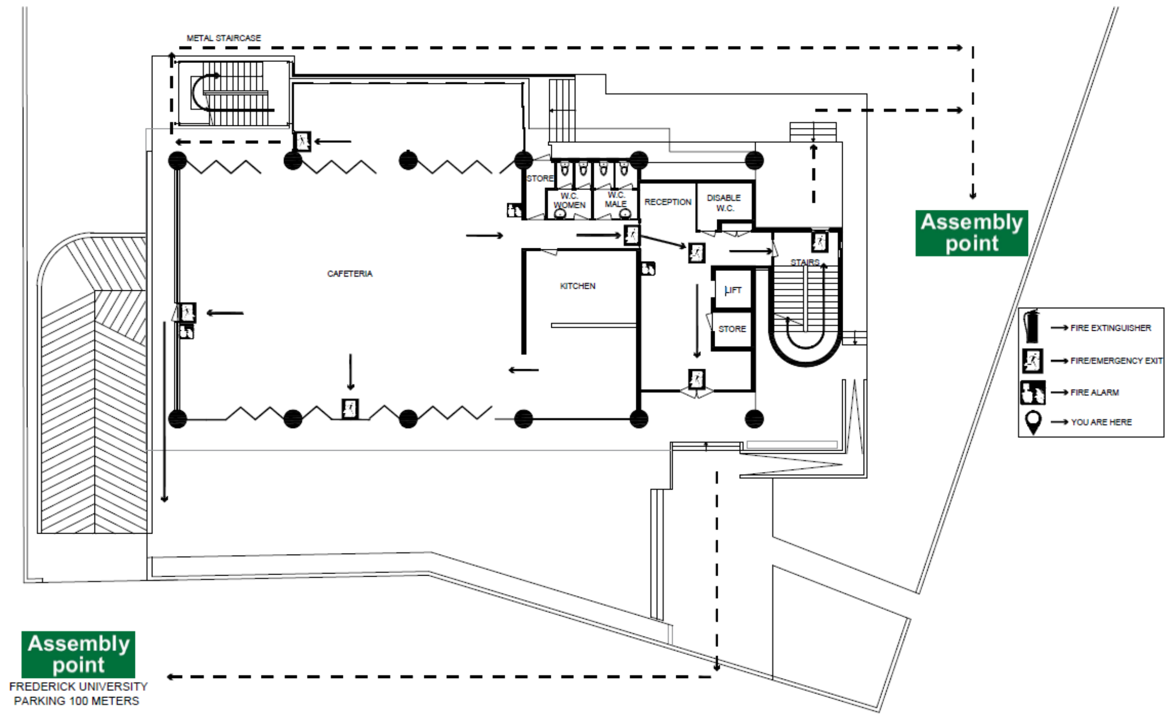


Figure 73: Floor plan - Ground floor

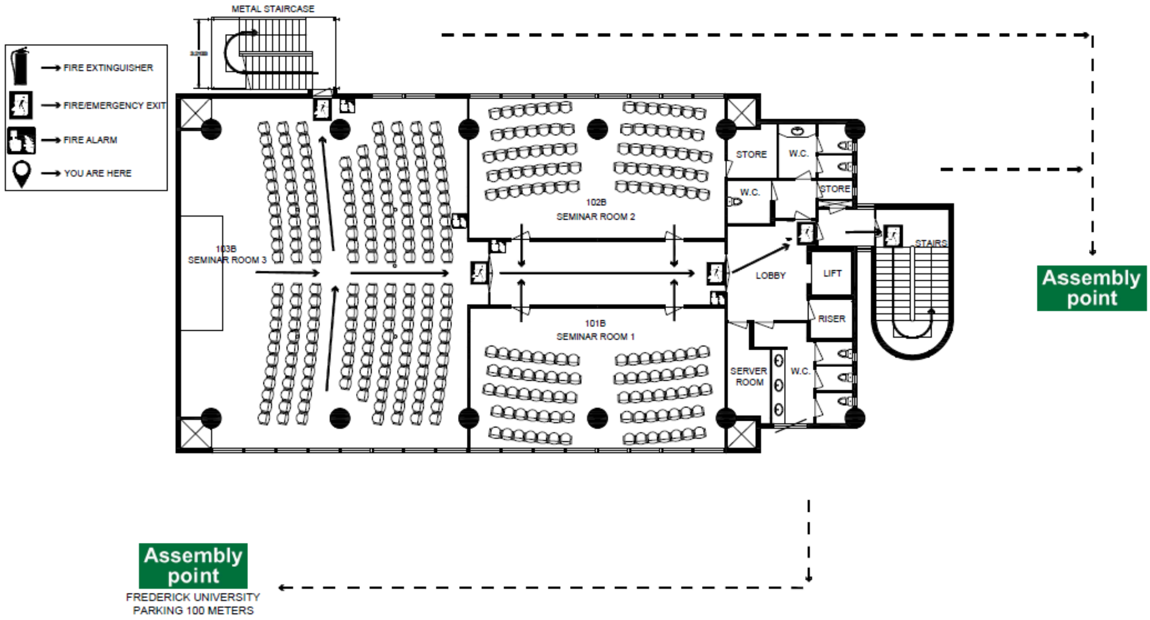


Figure 74: Floor plan - 1st floor

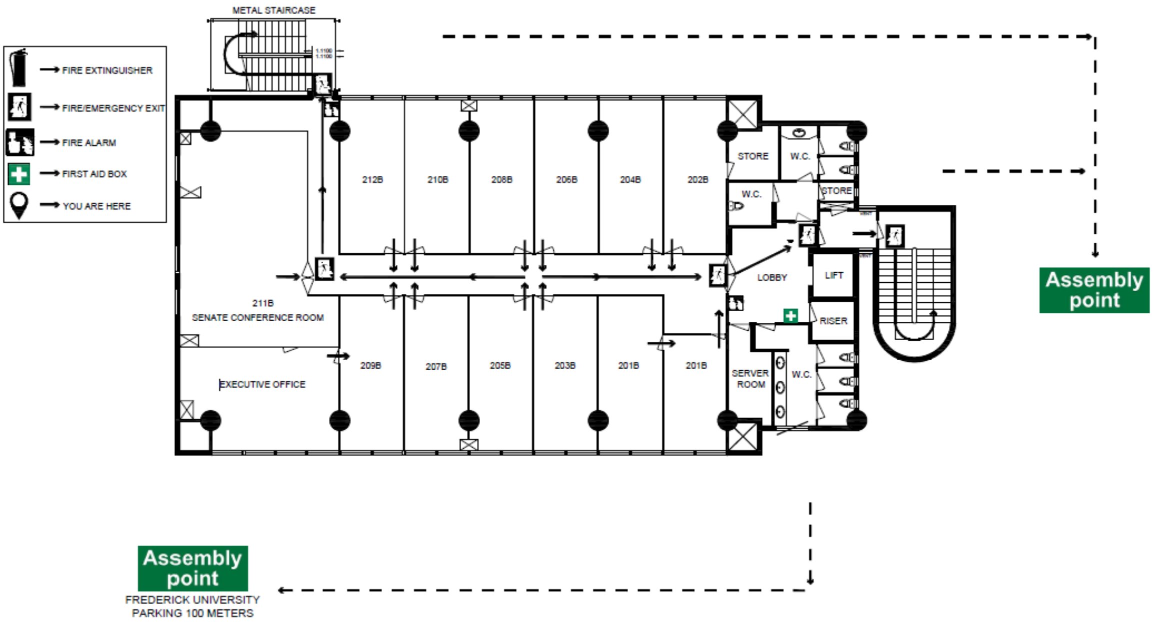


Figure 75: Floor plan - 2nd floor

A photorealistic representation of the building is demonstrated in Figure 76 and Figure 77. The presentations derive from the IFC file 3-D visualization in a BIM environment.

Figure 76: IFC model of a FRC building (1)

Figure 77: IFC model of a FRC building (2)

7.3 Building Envelope

The design and construction of the building envelope have taken into consideration all the aspects that ensure safe and energy-efficient construction. The BIM materials are matched with the LCA library materials, and the information about the quantities and type of material are transferred for the needs of this document. Before proceeding with the analysis, a check of the correct matching of the materials has been made, as well as entering data in the Benchmarks tab, such as the area, the country, and the type of the investigated building. All the results of the indicators were received via tables and graphs and below is the list of building parts and the BIM software database.

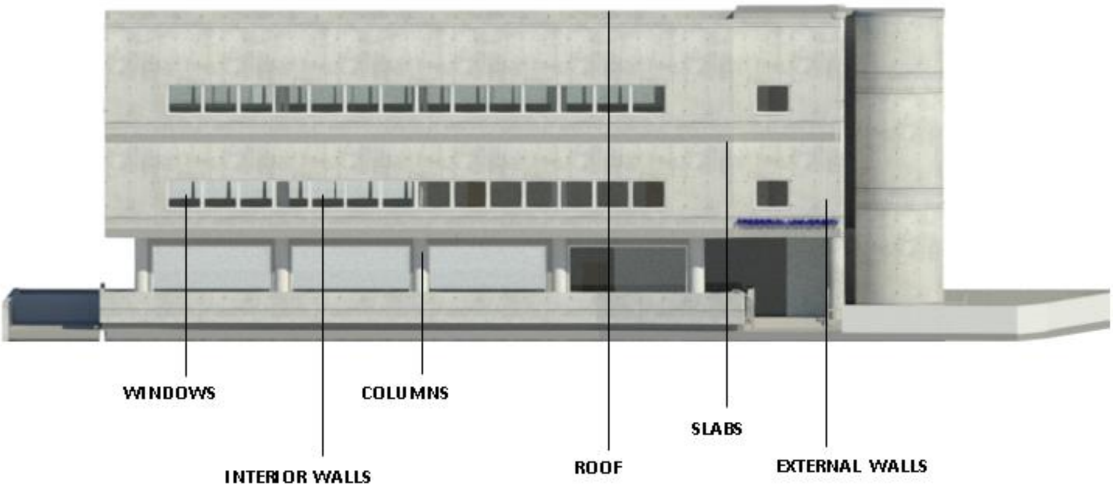


Figure 78: FRV building's parts

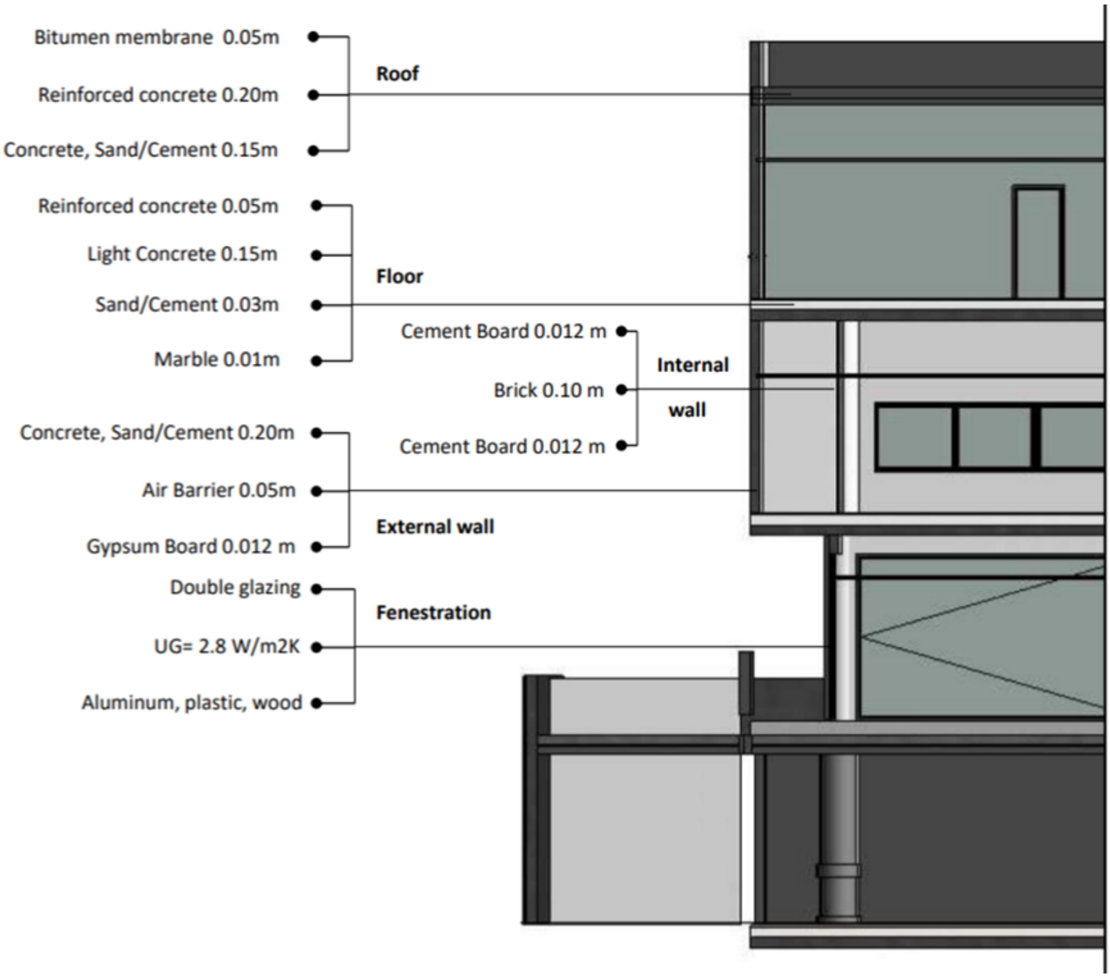
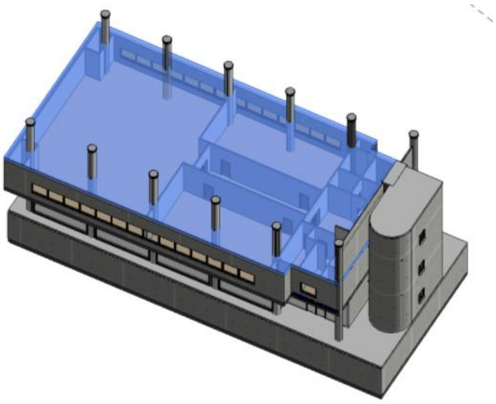
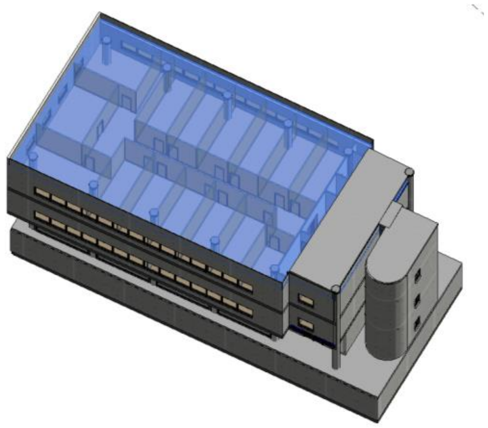


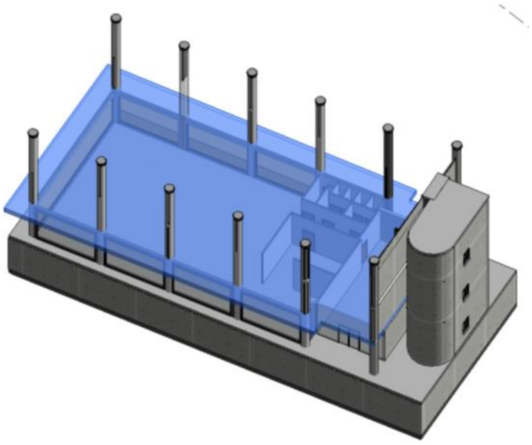
Figure 79: Building envelope of the FRC building



1st floor



2nd floor



Ground floor

Figure 80: FRC Building Floors

Table 15: List of construction materials according to the REVIT software database

STRUCTURAL TYPE	MATERIAL
SLAB	Metal - Stud Layer
SLAB	Plasterboard
SLAB	Air Barrier - Air Infiltration Barrier
SLAB	Ceramic Tile
SLAB	Concrete, Sand/Cement Screed
WINDOW	Glass
WINDOW	Window Frame
COLUMN	Glass
COLUMN	Plasterboard
COLUMN	Concrete, Sand/Cement Screed
COLUMN	Gypsum Wall Board
EXTERNAL WALL	Concrete, Sand/Cement Screed
EXTERNAL WALL	Gypsum Wall Board
EXTERNAL WALL	Metal - Aluminum
EXTERNAL WALL	Glass
EXTERNAL WALL	Masonry - Concrete Block
ROOF	GRC - Glass Reinforced Concrete
ROOF	Concrete - Sand/Cement Screed

ROOF	GFRC
DOOR	Door - Frame/Mullion
DOOR	Door - Handle
DOOR	Door - Glazing
DOOR	Door - Architrave
DOOR	Door - Panel
DOOR	Door - Frame
DOOR	Glass

7.3.1 External Walls

The description of all external wall layers materials concerning the kind of material, the thickness, as well as the conductivity coefficient are presented in Table 16 and in Figure 81 (from inside out) below. The total thickness of the wall is 0.2620 m, the resistance is 0.6940 m^{2}K/W and the thermal mass is 29.11 kJ/K.

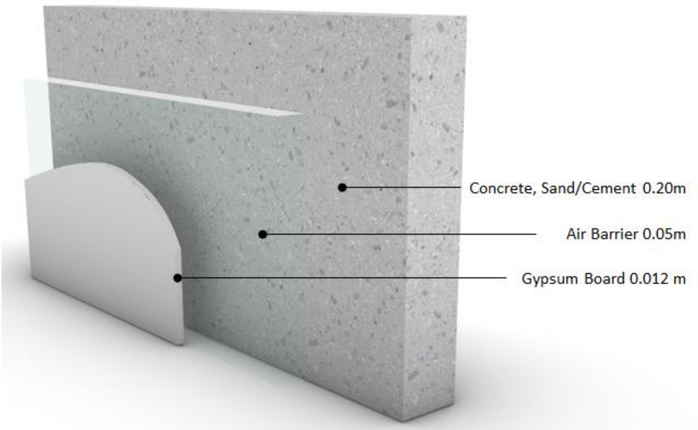


Figure 81: External wall interface from inside out

Table 16: List of construction materials of external walls according to the REVIT software database

Structural elements		Exterior masonry		
Function	**Materials**	**Material thickness d (m)**	**Thermal conductivity λ (W/Mk)**	**Thermal resistance R (m^{2}K/W)**
Structure	Concrete, sand , cement screed	0.03	1	0.03
Thermal/ Air layer	Air barrier/ Air in flit	0.0500	-	-
Finish	Gypsum wall board	0.012	0.2	0.06
Heat flow		**R_{si} (W/m^{2}K)**	**R_{se} (W/m^{2}K)**	**U-value (W/m^{2}K)**
Horizontal		0.10	0.04	1.44

7.3.2 Internal Walls

The description of all internal wall layers concerning the kind of material, the thickness, as well as the conductivity coefficient, are presented in Table 17 and in Figure 82 (from inside out) below. The total thickness of the wall is 0.12 m, the resistance is 0.5290 m^{2}K/W and the thermal mass is 17.70 kJ/K.

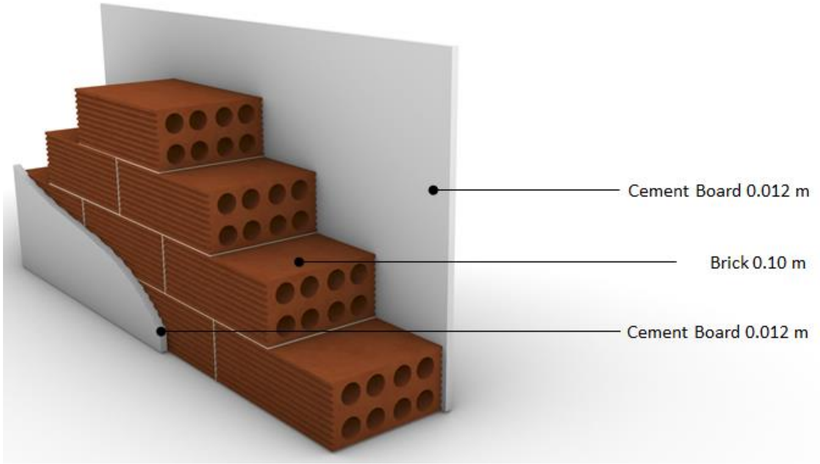


Figure 82: Internal wall interface from inside out

Table 17: List of construction materials of internal walls according to the REVIT software database

Structural elements		Exterior masonry		
Function	**Materials**	**Material thickness d (m)**	**Thermal conductivity λ (W/Mk)**	**Thermal resistance R (m^2K/W)**
Finish	Cement board	0.0120	0.2	0.06
Structure	Masonry, concrete brick	0.100	4	0.5
Finish	Cement board	0.0120	0.2	0.06
Heat flow		**R_{si} (W/m^2K)**	**R_{se} (W/m^2K)**	**U-value (W/m^2K)**
Horizontal		0.10	0.04	1.92

7.3.3 Roof

The description of all roof layers concerning the kind of material, the thickness, as well as the conductivity coefficient are presented in Table 18 and in Figure 81(from inside out) below. The total thickness of the wall is 1.550 m, the resistance is 0.7982 m^2K/W and the thermal mass is 22.11 kJ/K, and there is no insulation material.

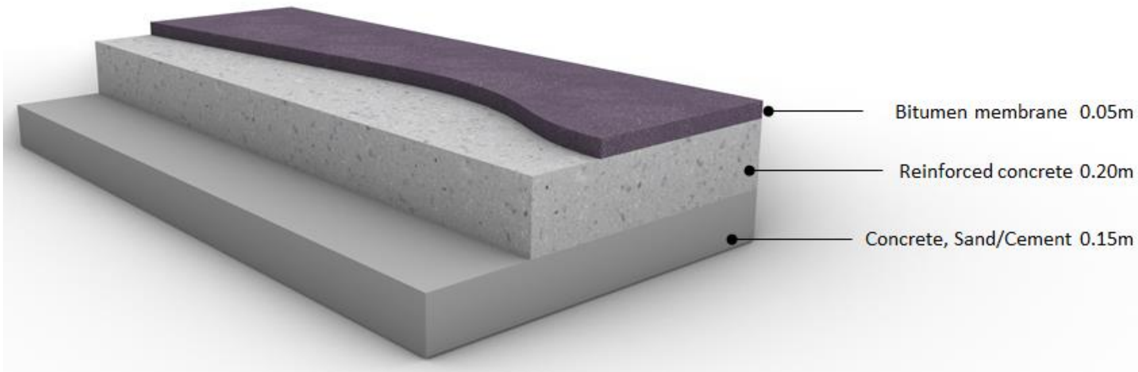


Figure 83: Roof interface from inside out

Table 18: List of construction materials of roof according to the REVIT software database

Structural elements		Exterior masonry		
Function	Materials	Material thickness d (m)	Thermal conductivity λ (W/Mk)	Thermal resistance R (m^2K/W)
Membrane layer	Bitumen membrane	0.0050	0.23	0.022
Structure	Glass reinforced concrete	0.2000	2.3	0.022
Structure	Concrete, sand , cement screed	1.1500	1	0.03
Heat flow		R_{si} (W/m^2K)	R_{se} (W/m^2K)	U-value (W/m^2K)
Vertical		0.10	0.04	1.67

7.3.4 Floor

The description of all floor layers concerning the kind of material, the thickness, as well as the conductivity coefficient are presented in Table 19 and Figure 84 (from inside out) below. The resistance is 0.487 m^2K/W and there is no insulation material.

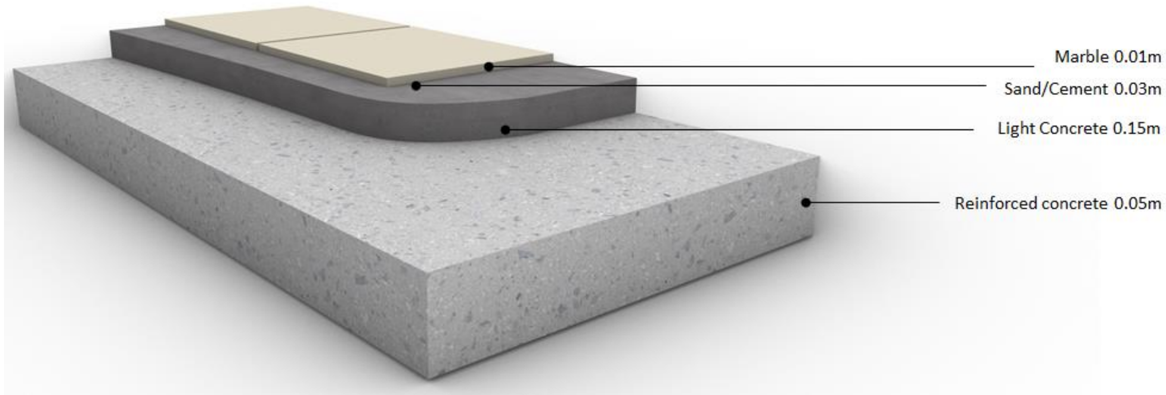


Figure 84: Floor interface from inside out

Table 19: List of construction materials of roof according to the REVIT software database

Structural elements		Exterior masonry		
Function	Materials	Material thickness d (m)	Thermal conductivity λ (W/Mk)	Thermal resistance R (m^2K/W)
Membrane layer	Concrete reinforced with 1% steel	0.05	2.3	0.022
Structure	Lightweight concrete	0.15	0.18	0.833
Structure	Sand, cement screed	0.03	1	0.03
Finish	Marble	0.01	3.5	0.003

7.3.5 Fenestration

Concerning the fenestration of the FRC pilot building, double-glazing types were used in the whole building of 1810×1210 mm distances and a heat transfer coefficient of 2.8 W/m^2K. There are three types of frameworks: horizontal sliding, pop-ups and sealed windows made of aluminum, plastic and wood, respectively. Additionally, there is no type of air isolation.

7.3.6 Structural elements environmental impact results

With the use of One click LCA software, the following data concerning the environmental indicators during the stage of construction/installation of construction materials for each category of structural elements of the building are presented in Table 20.

Table 20: Table of environmental indicators during the stage of construction/installation of construction materials for each category of structural elements of the building

Construction	User input	Global warming kg CO_2e	Biogenic carbon storage kg CO_2e bio	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Abiotic depletion potential (ADP-elements) for non fossil resources kg Sbe	Abiotic depletion potential (ADP-fossil fuels) for fossil resources MJ
Building materials > Vertical structures and facade > External walls and facade									
	Section total	1,74E4		1,77E−3	1,17E2	1,34E1	5,39E0	1,5E1	1,65E5
Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
	Section total	1,64E3		1,26E−4	5,7E0	2,13E0	2,98E−1	4,48E−1	2,55E4
Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
	Section total	1,37E4		2,35E−3	3,55E1	3,42E0	1,86E1	4,06E1	2,3E5
Building materials > Other structures and materials > Other structures and materials									
	Section total	2,46E1		1,66E−6	8,67E−2	8,37E−3	3,28E−3	8,73E−3	1,8E2
Building materials > Other structures and materials > Windows and doors									
	Section total	2,99E4		4,2E−3	2,5E2	1,65E1	1,27E1	7,66E−1	3,41E5

7.4 Building Equipment

In this section, all the electric and mechanical devices or units of the building are presented. Every sensor that gathers measurements concerning both indoor and outdoor environment conditions is included. The building's metering energy consumption (power metering), as well as a detailed examination of the technical units monitoring the users' indoor conditions are described as follows.

7.4.1 Sensors

In the FRC building, there are 30 input meter data loggers and 45 input meter core data loggers for measuring the energy performance of the building, while 3-zone monitoring and remote sensors are responsible for measuring carbon dioxide, temperature, and relative humidity. The measurements started in the middle of June 2021. The measurement data are displayed in Table 25. Based on the measured values, the existing sensing equipment is categorized as follows.

On the ground floor, there are two measurements available, one for the canteen and one for the elevator. The canteen values include all the appliances and lighting in this area. On the first floor, the measurements are divided into lights and sockets, where lights are further divided into three different lecture rooms and utility areas (WC, server room, store, etc.). The lights and sockets are summed up under item Usage. The same division can be found on the second floor and measurements on the roof are related to the energy, used for the VRVs air conditioning system. Three of them are on the ground floor and two are on the second floor. The VRVs on the first floor are also installed and the measurement results have been provided.

The measurements for the lightning and appliances on the first and second floors, as well as HVAC data on the ground and second floor, started on 16^{th} June 2021, while measurements for the canteen and elevator on the ground floor started on 23^{rd} October 2021. The measurements for the HVAC on the first floor are starting later in the project.

Table 21: Measurement data for FRC building

Floor	Item			Measurements
Ground floor	Usage			- Canteen - Elevator
1^{st} floor	Usage	1^{st} floor total lights	Lecture Theatre Large Lights	- Lecture Theatre L LIGHTS1 m11 - Lecture Theatre L LIGHTS2 m13 - Lecture Theatre L LIGHTS3 g13 - Lecture Theatre L LIGHTS4 g14
			Lecture Theatre Small N Lights	- Lecture Theatre N LIGHTS1 k6 - Lecture Theatre N LIGHTS2 m8
			Lecture Theatre Small S Lights	- Lecture Theatre S LIGHTS1 m6 - Lecture Theatre S LIGHTS2 k11
			Utilities	- Lecture Corridor LIGHTS k7 - Utilities South LIGHTS g11 - Utilities North LIGHTS k13
		- 1^{st} floor sockets		
2^{nd} floor	Usage	Lights total POWER		- Lights OFFICE 1 - Lights OFFICE 2 - Lights OFFICE 2 - Lights UTILITIES 1 - Lights MEETING ROOM - Lights OFFICE 12 - Lights OFFICE 6 - Lights PRINCIPAL OFFICE - Lights CORRIDOR - Lights OFFICE 10 - Lights OFFICE 5 - Lights OFFICE 3 - Lights OFFICE 7 - Lights OFFICE 11 - Lights UTILITIES 2 - Lights UTILITIES 3 - Lights OFFICE 4 - Lights OFFICE P1 - Lights OFFICE 8
		- 2nd Floor Sockets		

Roof	Usage	- Power EVRV-G3| - Power EVRV-G2| - Power EVRV-G1| - Power VRV-2F2| - Power VRV-2F1|

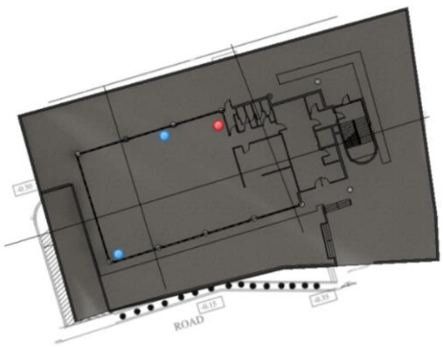
Table 22 Monitoring equipment characteristics

Name	Accuracy	Qty	Picture
Hobo EG4115 Core Data Logger	0.5% revenue-grade accuracy compliance	3	
Hobo EG4130Pro Data Logger	0.5% revenue-grade accuracy compliance	1	
Hobo T-EG-0630-0100	Up to +/-1%	21	
Hobo T-EG-0940- 0100	Up to +/-1%	3	
Hobo T-EG-0940- 0200	Up to +/-1%	3	
Hobo T-EG-0390-0050	Up to +/-1%	30	
AM107-868M Milesight AM107 (LoRaWAN®)	Temperature sensing: -40°C - 85°C, ± 1°C accuracy Humidity sensing: 0% – 100% RH, ± 3% accuracy CO2 sensing: 400 – 5000 ppm, ±30 ppm or ±3 %	7	

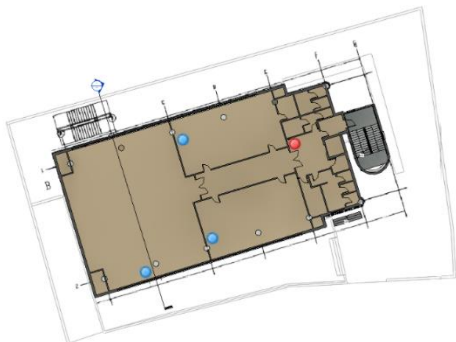
Presented herewith are the floor plans of the building along with the precise locations of the measuring devices.

Power meters

Indoor Ambience Monitoring Sensor
(Milesight AM107 LoRaWAN® with E-Ink Display) – Temperature, Humidity, and CO2

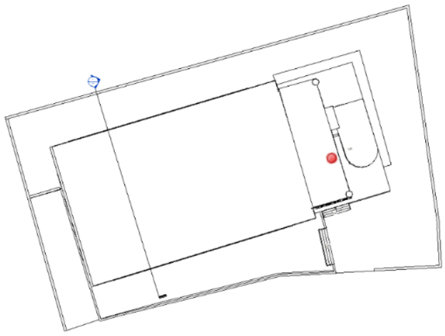


Ground Floor



First Floor

Second Floor



Roof

7.4.1.1 Temperature and Humidity

The sensors for indoor temperature and humidity measurements throughout the building are installed in each space. The grouping of measurements and storage to the IoT platform takes place periodically every 2 hours.

7.4.1.2 CO_2

CO_2 sensors are used to measure carbon dioxide levels in each space. The collection of measurements and storage to the IoT platform takes place periodically every 2 hours.

7.4.1.3 Luminance

The spaces' light levels are measured using dedicated luminance sensors. The collection of measurements and storage to the IoT platform takes place periodically every 2 hours.

7.4.1.4 Weather station

The weather station metering system, mounted on a building's roof pole, is used for measuring outdoor climate conditions, i.e. air temperature, air relative humidity, solar radiation, wind speed and direction. Data are retrieved every 2 hours.

7.4.2 Meters

As the Frederick University New Wing operates mostly on electrical energy to cover its demands (there is no use of a gas or oil-fired boiler) the main area of metering is associated with electricity.

7.4.2.1 Energy

Electrical energy usage is assessed both for the entire structure and for each individual floor. Additionally, the electricity consumption of the two existing HVAC systems is measured separately.

7.4.3 Systems

The primary technical systems that are used to produce the ideal interior conditions are presented in this section. The heating, cooling, and air-conditioning (HVAC) systems, as well as lighting and power outlets, are all described. Additionally, despite its minimal contribution to overall energy usage, there is a brief technical explanation of the enhanced elevator system in spite of its insignificant contribution to overall energy use.

7.4.3.1 Heating - Cooling

The HVAC system installed in FRC New Wing is a Variable Refrigerant Volume (VRV) air conditioning system, used for both heating and cooling of the two occupied floor spaces. All the ceiling mounted AC terminal units are 4-way cassettes type at the different spaces of the building with same geometry. The total amount of installed VRV units is 34, divided into 17 units on the first floor and 17 units on the second floor. The deployment of the heating and cooling equipment is presented in Figure 85, Figure 86 and Figure 87.

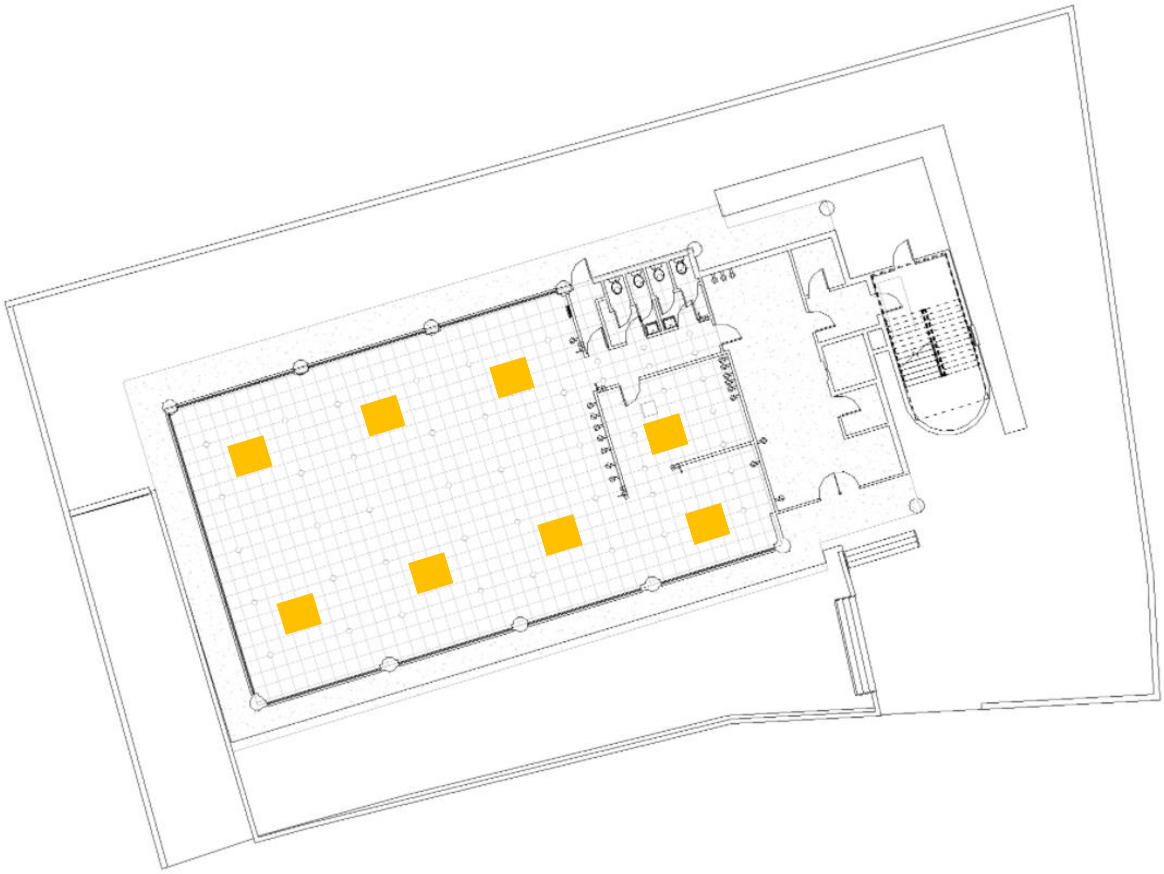


Figure 85: Ground floor HVAC

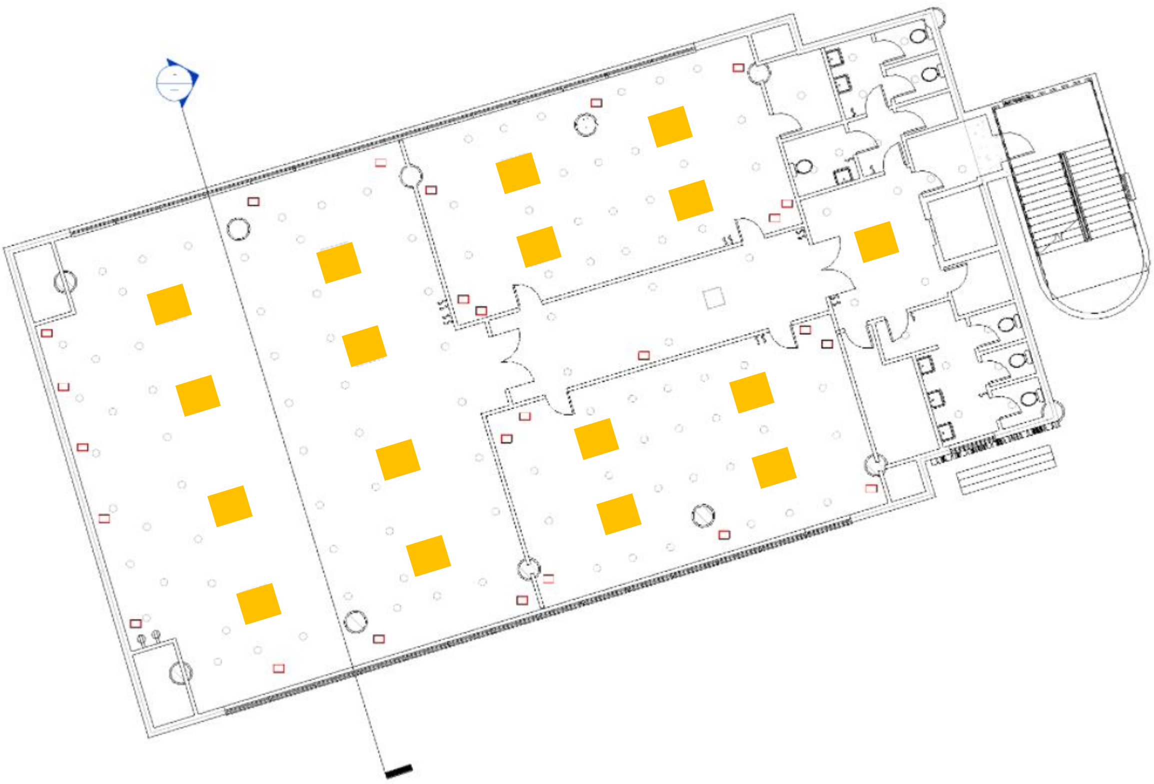


Figure 86: First floor HVAC

Figure 87: Second floor HVAC

7.4.3.2 Ventilation

The building does not have a mechanical ventilation system. Natural ventilation from the openings provides the essential indoor air change.

7.4.3.3 Lighting

The lighting installation has two system types in the two floor spaces according to their use. The lighting requirements at the office spaces are more demanding. Thus, 86 square LED panels of 60x60cm have been installed in total, 1 on the ground floor and 85 in the offices on the second floor. Each panel has crosswise parabolic louvres and longwise double parabolic elements. Their shape is rectangular with dimensions, 600×600×95mm. Every device includes 4 LED lamps (fluorene type T8) with a power consumption of 10W each. In the seminar hall spaces, and common use areas, a total of 209 spotlight lighting units have been installed, 53 on the ground floor, 123 on the first floor and 33 on the second floor, respectively. Each spot is equipped with 2 LED lamps of 10 W each. Furthermore, the emergency lighting includes 4 EXIT LED (2 W). They are equipped with Ni-Cd batteries that are capable of providing lighting for 2 hours. The total power consumption of the building's lighting system is calculated to be equal to 1314 kWh per month. The deployment of the lighting equipment is presented in Figure 86, Figure 89 and Figure 90.

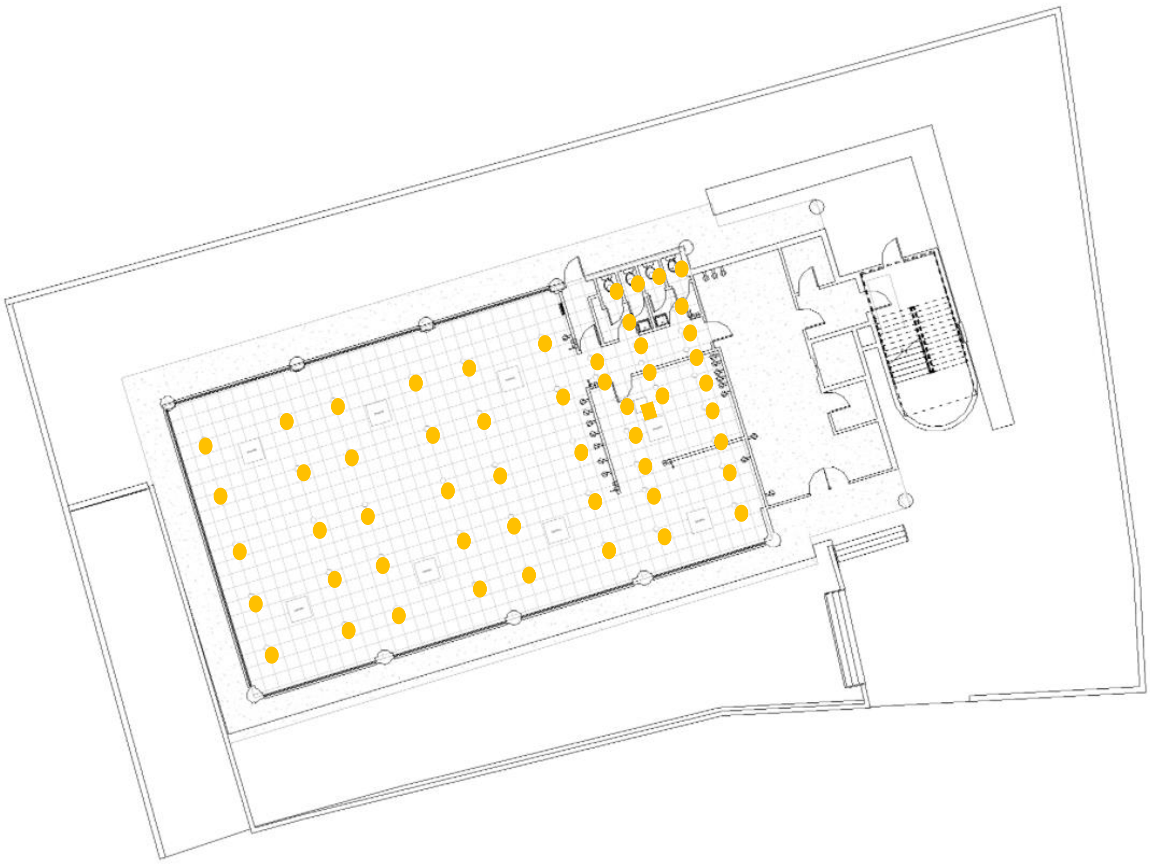


Figure 88: Ground floor lighting

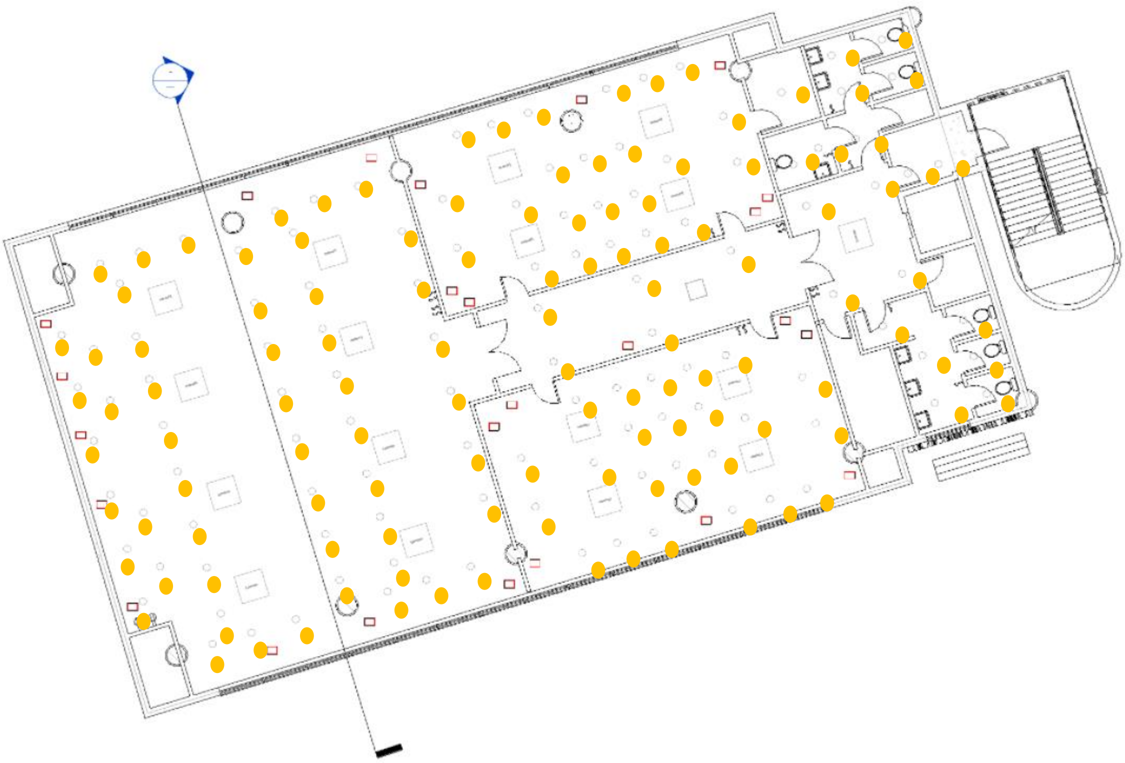


Figure 89: First floor lighting

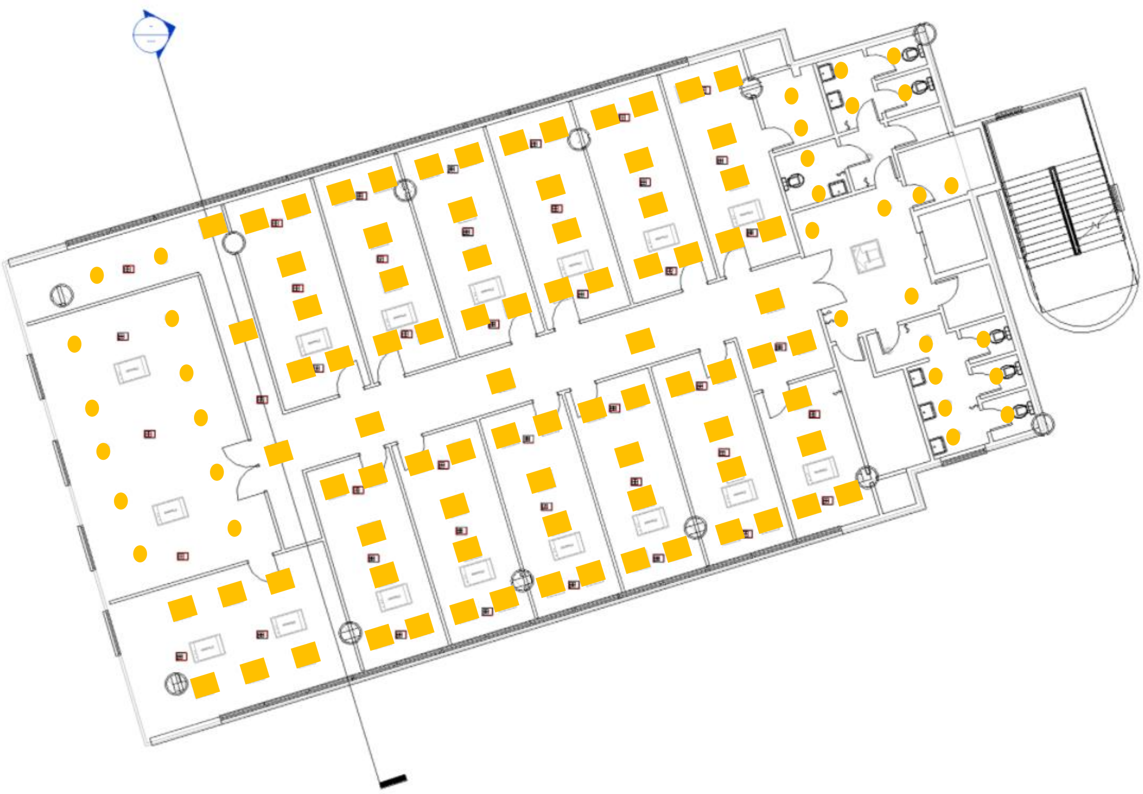


Figure 90: Second floor lighting

7.4.3.4 Sockets

The ground sockets are installed on the floor spaces for technical appliances equipment charging. There are in total 70 ground sockets; 25 on the first floor and 45 on the second floor (all of which include 4 outlets), respectively. Additionally, 20 power socket wall duplexes exist on the ground floor and 2 on the first floor. The deployment of the ground sockets for technical appliances equipment is presented in Figure 89, Figure 92 and Figure 93.

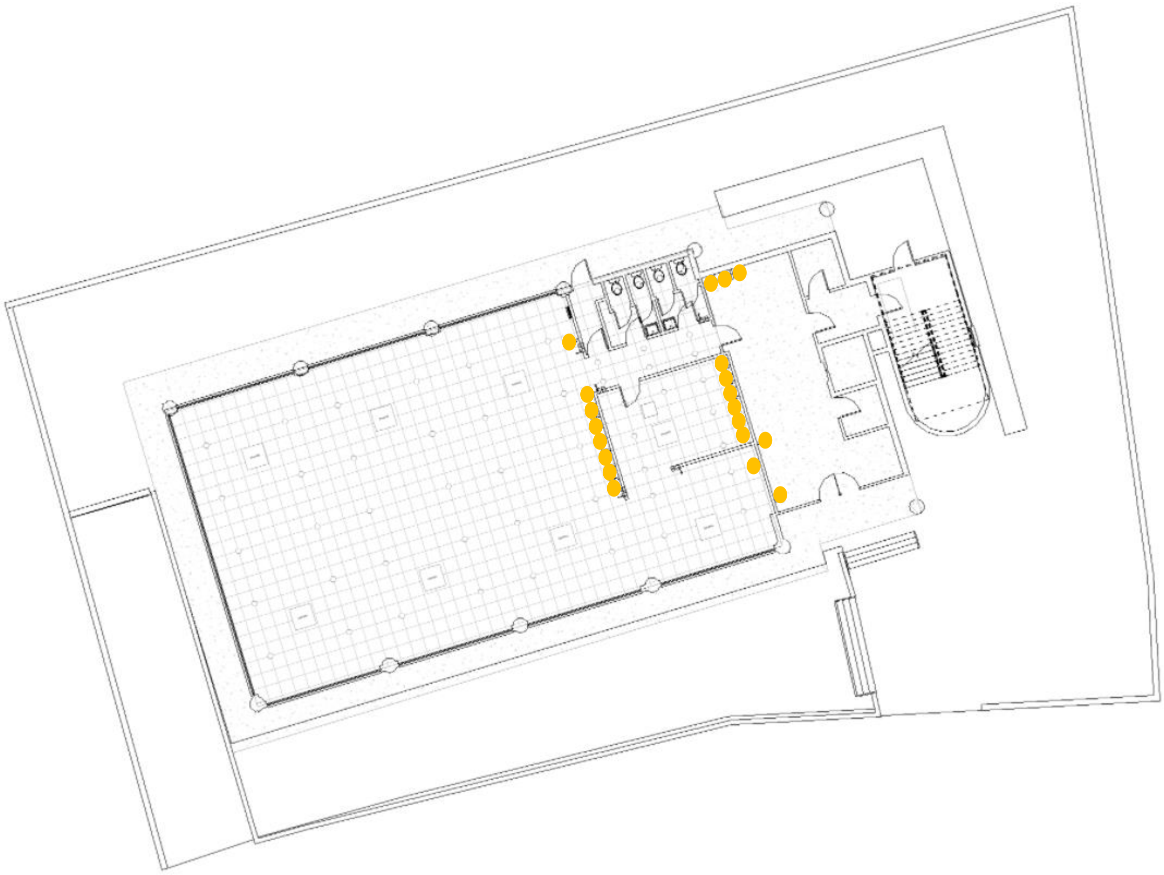


Figure 91: Ground floor power socket wall duplexes

Figure 92: First floor ground sockets

Figure 93: Second floor ground sockets

7.4.3.5 Elevator

The elevator is built to fulfil all of the relevant European and national standards for modern lifting systems, including the regulations for disabled individuals. The extra systems provide additional services to enable predictive maintenance and timely debugging by facilitating electrical and mechanical lift monitoring, as well as user interface features.

7.5 Pre-pilot LCA assessment

Based on the LCA analysis results according to Level(s) standards,
Table 23 and Table 24 below show in detail the values of the environmental indicators for the end-of-life stage, as well as the total values for each indicator. The tables are divided into 3 categories, the results for life-cycle assessment, as well as the usage of primary energy and water. Since the construction/installation process stage presented 0 values throughout the analysis, it is not included in these tables.

Table 23: Table of environmental indicators for environmental impact during the C1-C4 building deconstruction

	Result category	Global warming kg CO_2e	Biogenic carbon storage kg CO_2e bio	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Abiotic depletion potential (ADP-elements) for non fossil resources kg Sbe	Abiotic depletion potential (ADP-fossil fuels) for fossil resources MJ
C1-C4	**End of life**	1,94E4		1,61E−3	6,77E1	1,87E1	5,78E0	6,68E1	2,27E5

Table 24: Table of environmental indicators for the total of primary energy during the C1-C4 building demolition

	Result category	Use of renewable primary energy resources as raw materials MJ	Total use of primary energy ex. raw materials MJ	Total use of renewable primary energy MJ	Total use of non renewable primary energy MJ	Use of net fresh water m^3
C1-C4	**End of life**	0E0	2,9E5	9,97E3	2,8E5	3,66E1

In addition, Table 25 and Figure 94 have been issued on the values of environmental indicators separately for each material, as well as for the categories of structural elements of the building.

Table 25: Table of environmental indicators for each building material

Category	Screed, flooring	Ready-mix concrete, normal-strength,	Float glass, single pane, generic	HS2 baseline - Aluminium Mill-	Ready-mix concrete, normal strength,	Ceramic tiles highly sintered glazed and	Aluminum flat-rolled products, coil coated	Wooden stud framing system for external	Interior wooden door with frame and sills	Structural sawn timber, kiln dried,	Mastic asphalt	Processed glass, double-pane IGU	Other items
GWP	5.62	5.01	17.73	5.57	9.41	8.45	38.65	0.04	0.37	0.03	3.14	1.79	4.20
Bio-CO2 storage	0.00	0.00	0.00	0.00	16.34	0.00	0.00	33.56	28.11	21.98	0.00	0.00	0.00
ODP	5.58	3.16	13.41	6.57	5.89	16.87	46.76	0.05	0.16	0.00	0.30	0.07	1.19

AP	4.49	2.70	22.49	9.23	3.95	2.97	48.35	0.05	0.10	0.03	1.58	1.79	2.27
EP	5.64	3.04	21.51	14.16	8.10	1.64	36.38	0.07	0.27	0.04	1.66	3.22	4.26
POCP	2.51	1.44	11.09	6.12	2.65	37.00	34.15	0.03	0.19	0.02	0.33	1.55	2.93
ADPE	1.44	3.65	5.26	23.62	1.19	59.75	1.47	0.01	0.02	0.01	1.84	0.53	1.21
ADPF	3.70	3.06	16.83	4.64	4.95	15.19	34.70	0.04	0.14	0.03	10.26	2.84	3.62
PERM	0.00	0.00	0.00	81.72	0.00	0.00	0.00	10.10	0.00	6.58	0.00	1.02	0.60
Total use of primary energy ex. raw materials	6.37	4.46	29.75	0.58	1.74	12.44	27.48	0.12	0.48	0.07	5.86	5.55	5.08
PERT	1.96	1.00	4.71	9.94	0.69	3.12	69.39	1.74	1.09	1.01	1.93	1.35	2.10
PENRT	5.98	4.25	28.68	5.51	1.61	11.79	15.17	0.03	0.29	0.03	16.65	5.31	4.71
FW	0.37	0.32	1.00	0.38	25.04	0.28	3.16	0.00	0.03	0.00	0.02	69.27	0.12

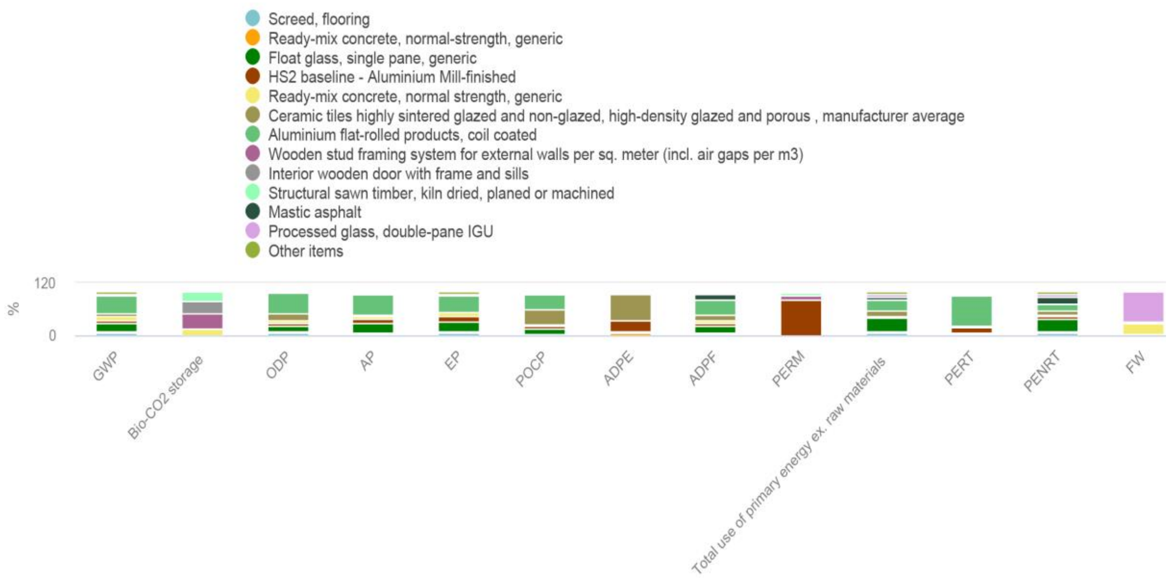


Figure 94: Graph of the values of environmental indicators for each building material

Through the values is observed the environmental footprint for each construction material and each category of structural element (Table 26 and Table 27).

Table 26: Table of environmental indicators during the stage of construction/installation of construction materials for each category of structural elements of the building

Construction	User input	Global warming kg CO_2e	Biogenic carbon storage kg CO_2e bio	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Abiotic depletion potential (ADP-elements) for non fossil	Abiotic depletion potential (ADP-fossil fuels) for fossil

								resources kg Sbe	resources MJ
Building materials > Vertical structures and facade > External walls and facade									
	Section total	1,74E4		1,77E−3	1,17E2	1,34E1	5,39E0	1,5E1	1,65E5
Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
	Section total	1,64E3		1,26E−4	5,7E0	2,13E0	2,98E−1	4,48E−1	2,55E4
Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
	Section total	1,37E4		2,35E−3	3,55E1	3,42E0	1,86E1	4,06E1	2,3E5
Building materials > Other structures and materials > Other structures and materials									
	Section total	2,46E1		1,66E−6	8,67E−2	8,37E−3	3,28E−3	8,73E−3	1,8E2
Building materials > Other structures and materials > Windows and doors									
	Section total	2,99E4		4,2E−3	2,5E2	1,65E1	1,27E1	7,66E−1	3,41E5

Table 27: Table of environmental indicators during the stage of decomposition of construction materials for each category of structural elements of the building

Construction	User input	Global warming kg CO_2e	Biogenic carbon storage kg CO_2e bio	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Abiotic depletion potential (ADP-elements) for non fossil resources kg Sbe	Abiotic depletion potential (ADP-fossil fuels) for fossil resources MJ
Building materials > Vertical structures and facade > External walls and facade									
	Section total	1,11E4		1,03E−3	3,39E1	1,07E1	3,01E0	4,44E1	1,24E5
Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
	Section total	1,03E3		1,21E−4	3,69E0	1,04E0	2,72E−1	5,24E0	1,31E4
Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
	Section total	2,43E4		4,22E−3	1,06E2	2,22E1	4,85E0	1,42E1	6,21E5
Building materials > Other structures and materials > Other structures and materials									
	Section total	3,17E1		5,9E−6	1,02E−1	2,45E−2	2,85E−3	2,17E−1	4,93E2
Building materials > Other structures and materials > Windows and doors									
	Section total	2,56E3		5,14E−5	2,3E0	9,65E−1	2,73E−1	2,79E0	6,77E3

Also, a basic value of environmental indicator of the building is exported from the One Click LCA analysis the energy class. The New Wing building (Figure 95) is based on the EN 15978/ISO 21930 standards as the basis of measurement, and includes life-cycle stages A1-A3, A4, B4-B5, and C1-C4. This card covers the impacts from material production, the replacement and/or refurbishment due to the end of the material's service life, and the end-of-life stage.

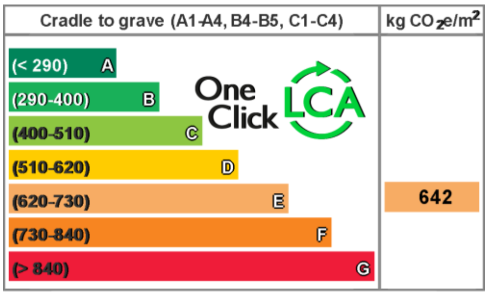


Figure 95: Energy class of New Wing Building

7.6 Pre-pilot EPC assessment

The New Wing building strives to minimize its energy consumption while also providing very environmentally friendly internal conditions thanks to its creative architectural design in conjunction with the use of highly efficient technical systems. As a result, the New Wing has achieved a good rating in the EPC evaluation process (Class C). The total annual consumption of primary energy in the building is 253 kWh/m^2/yr. The energy consumption of conventional energy sources is 252 kWh/ m^2/year and RES is 1 kWh/m^2/yr. The results from the National Asset Rating Methodology are presented below in Figure 94.

The certification is aligned to the Cypriot national standards, which are based on the EN ISO 13790. The software that was used for the certification is iSBEMcy v3.4.a which is developed by BRE. The competent authority for keeping and maintaining the Register of EPCs of buildings is the Energy Agency of the Ministry of Commerce, Industry and Tourism. The certification procedure has been conducted by Frederick University.

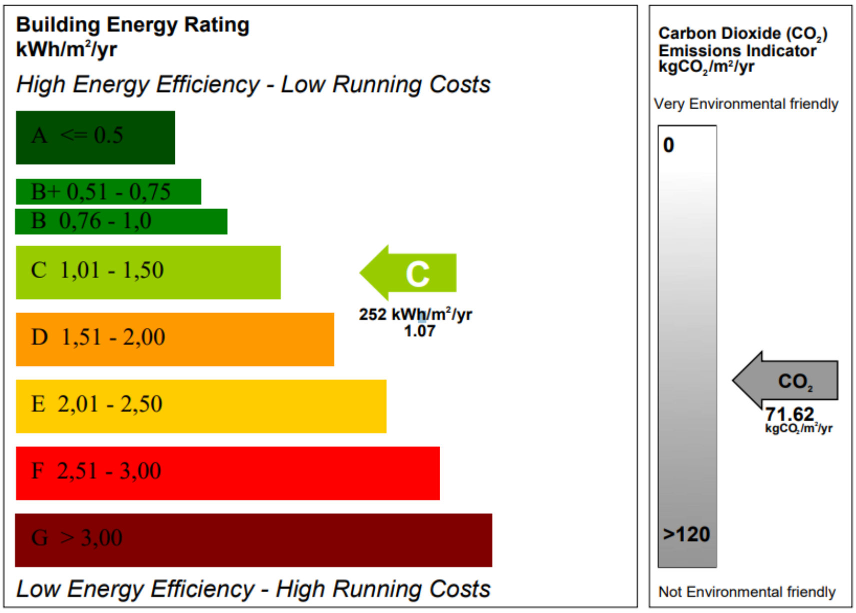


Figure 96: New Wing Energy Class

7.7 Pre-pilot SRI assessment

The Frederick University New Wing building has also been assessed by the SRI certification scheme prior to the latest installations which shows the scores it received in each domain, as well as the influence of its functioning on the occupants and other aspects (energy saving, flexibility etc.). The

SRI score of the New Wing building is quite low (52%). The New Wing building's SRI certification system is currently being revised; the most recent results are shown in Figure 95.

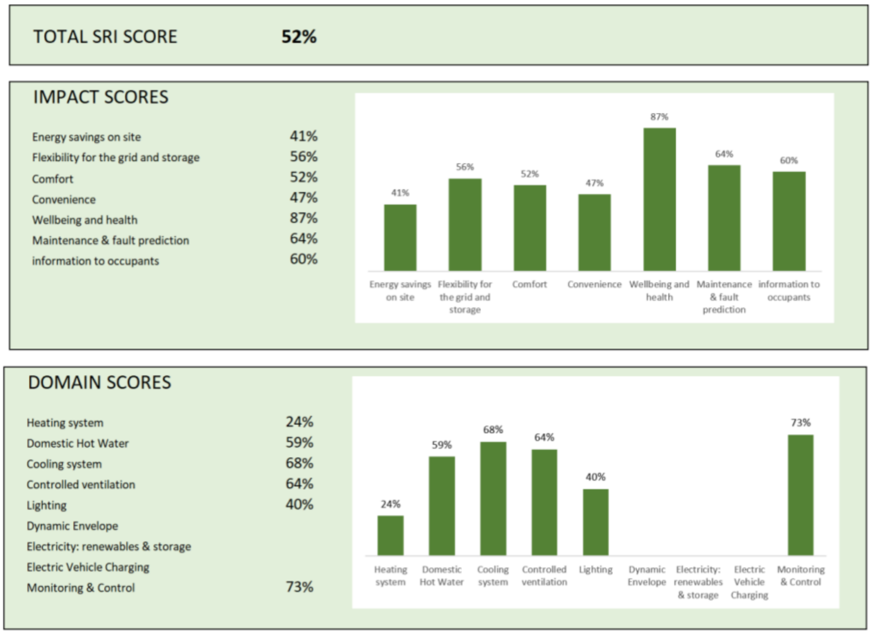


Figure 97: SRI score of New Wing building

7.8 Scenarios Deployment

CS4 had an extended monitoring infrastructure installed quite early during the pilot preparation period, which facilitated the provision of actual building measurements in terms of energy consumption and indoor conditions. The building served as the first application example of the operational rating methodology as well as of LCA, providing useful guidelines for the development of the corresponding tools and their implementation to the other case studies. Evidently, it fulfilled the following use cases deployment prerequisites:

- *Complete BIM file delivery*: the building's IFC file was already available by the project's initiation and included most of the required information. Within the pilots' preparation period, a small number of modifications and extensions were applied to better serve the needs of the project.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: The existing platform allowed the collection of measurements at local level quite early, whose time period reached one year and allowed to assess the as-operated performance of the building. Following, additional work was required to provide real-time access to the IML, in order to establish continuous data flow to the D^2EPC Web Platform.
- *Provision of historical data*: in anticipation of the connection to the IML component, historical data collected locally were provided and uploaded manually to the Web Platform for the early provision of as-operated EPC results.

Figure 98 displays the digital twin of Case Study 4, combining the BIM literacy with real-time data. More information about the deployment prerequisites can be found in D5.8 "D^2EPC Pilots Demonstration v2".

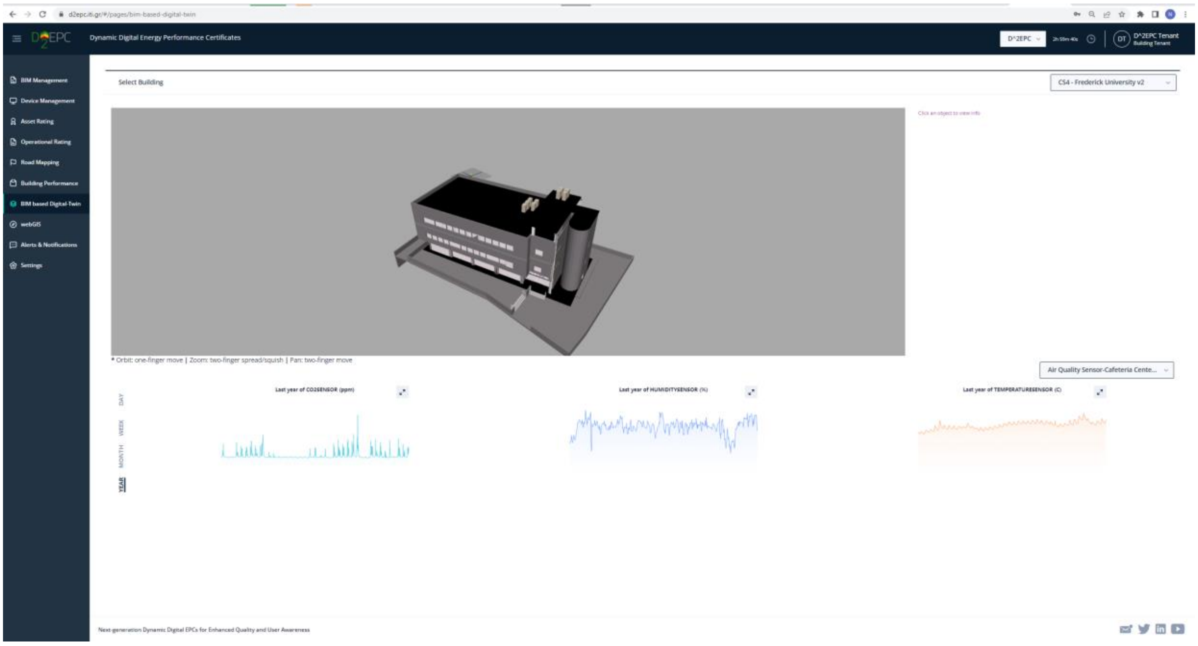


Figure 98: BIM-based Digital Twin of CS4

8 Case Study #5: Multi-family home in Berlin Germany

8.1 Objectives and Scope

The fifth pilot building is a multifamily building located at 13817 Berlin-Pankow, Mendelstraße 5. The distinctive characteristic of this case study is the building's age, as it was erected in 1900. In the last decade, the building has been renovated. Even though the building has great historical importance, there is a lack of extensive documentation that may create some challenges concerning its energy assessment. The building utilizes electricity and gas utilities to cover its energy demands. Consequently, it can serve as a showcase for the calculation of the operational rating-based EPC.

8.2 Topology

The building has a total area of 2929 m^2 and 17 apartments are hosted in it. All the apartments are considered as one thermal zone, because they have the same use (residential). The rest of the building is considered as an unheated thermal zone, which includes the staircase and the basement. Further information about the thermal zoning of the building is presented in Table 28.

Table 28: Zones of the building

Zone	Spaces
Residential	Living room, Kitchen, Guest Room, WCs, Single Bedroom, Double Bedroom, Game Room, Bathroom, Halls- Staircase
Unheated	Staircase Basement: Plenums (storage compartments), Boiler Room, Unused laundry room

As presented in the following floor plans (Figure 101 -Figure 105), the building construction has an "L" shape. The front view of the building is facing the Mendelstraße street (Figure 99), while the back view is facing a backyard (Figure 100). Sideways, the construction is in contact with neighboring buildings. The renovation results are also notable in the last two figures.

Figure 99: Front view

Figure 100: Rear view

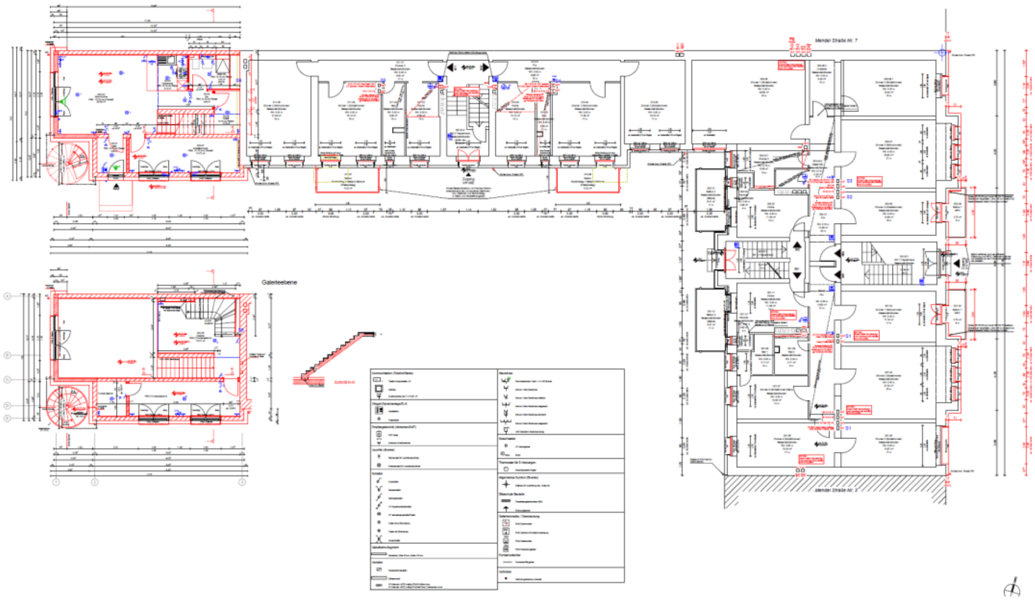


Figure 101: Ground Floor

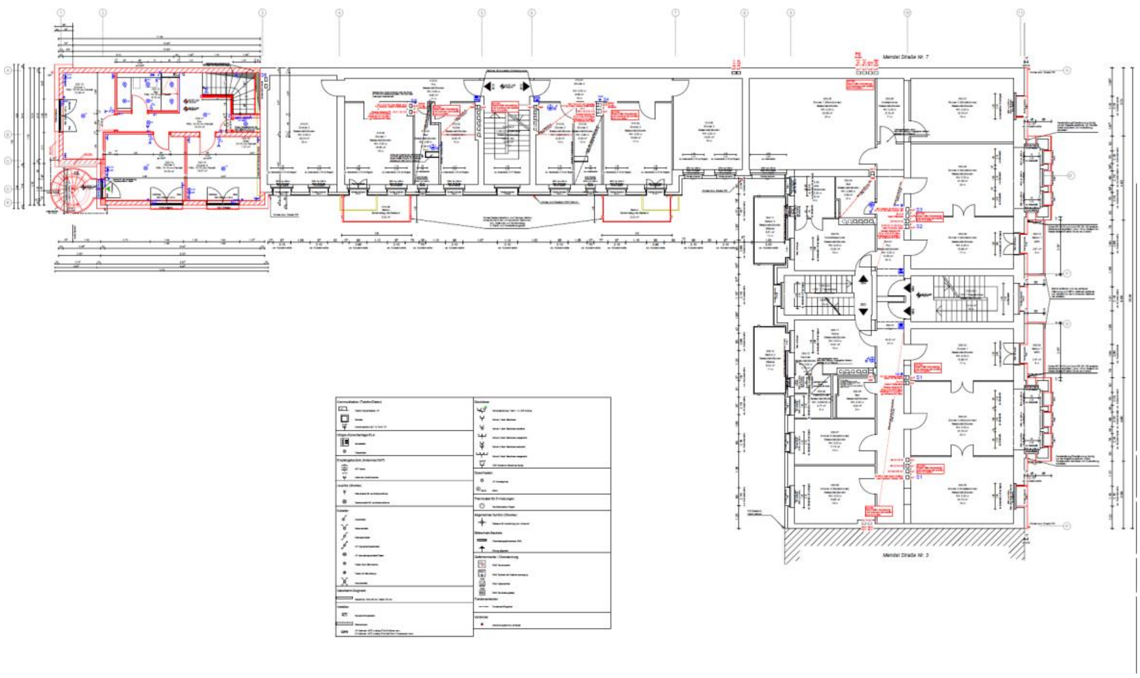


Figure 102: First floor

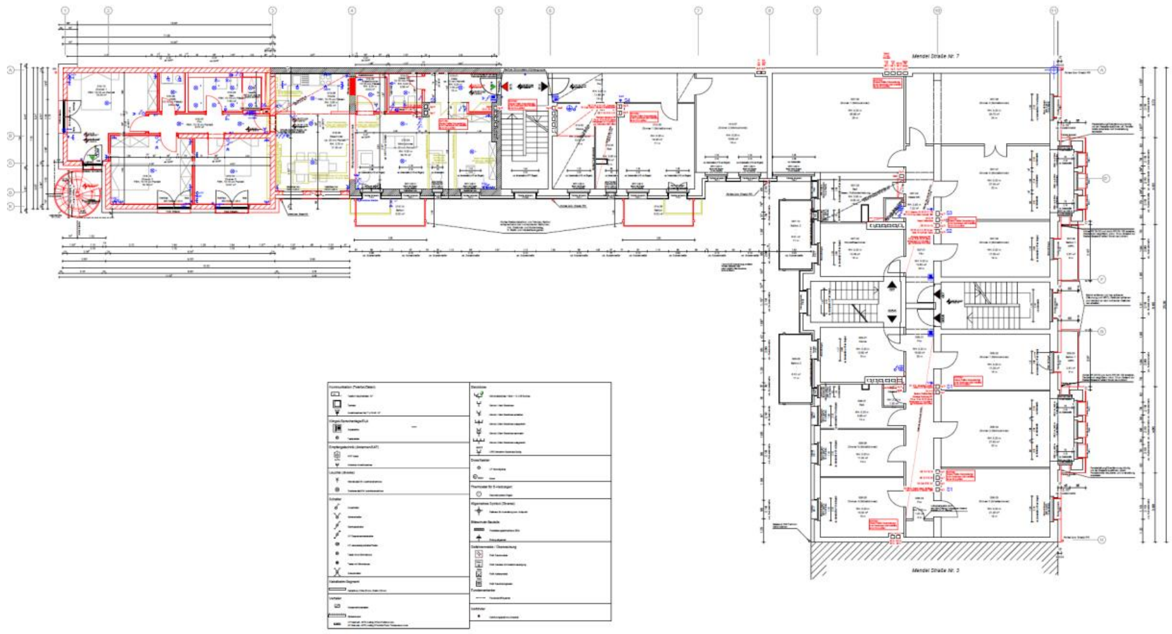


Figure 103: Second floor

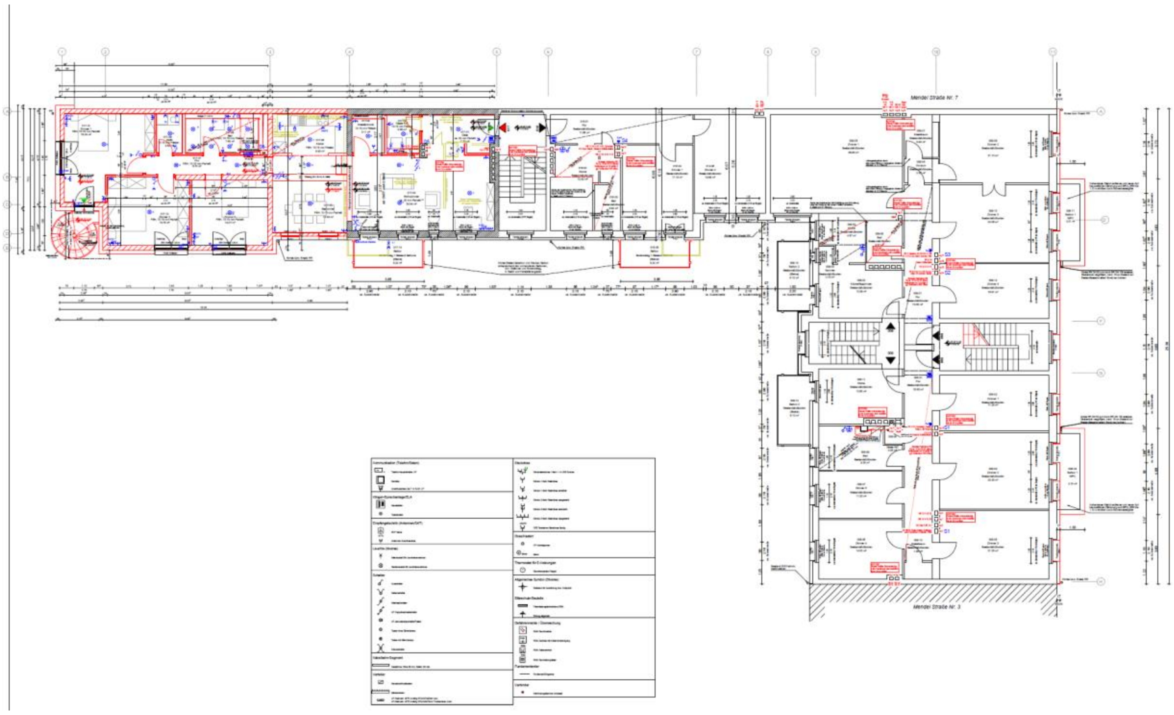


Figure 104: Third floor

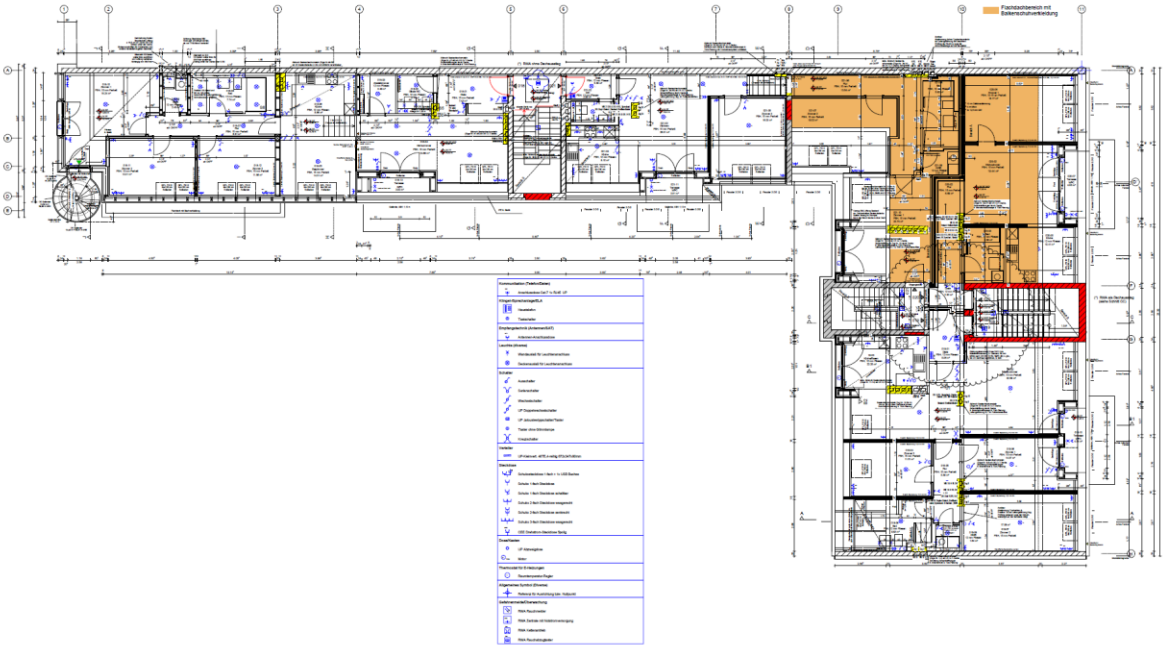


Figure 105: Top floor

A BIM model has been designed within the scope of D^2EPC. In the model, as much as possible information has been incorporated that existed in the building's drawings (geometrical information) and from previous energy assessments (thermal characteristics of building elements, technical characteristics of systems). The 3D representation of the BIM model is presented in Figure 106.

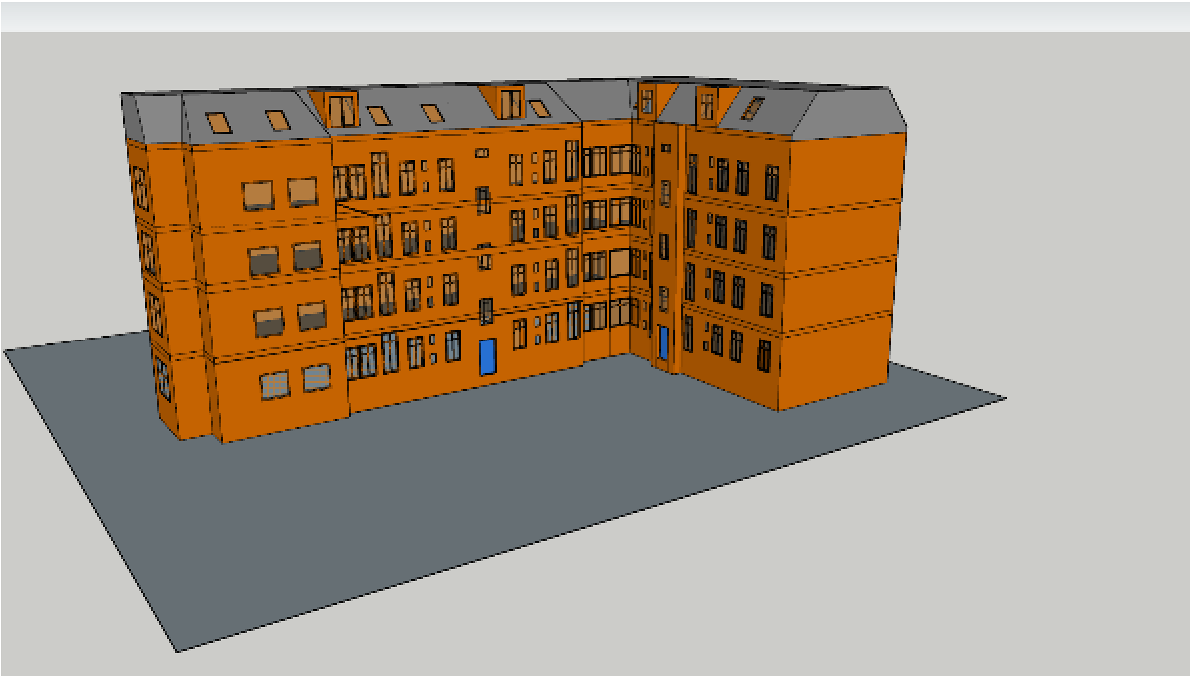


Figure 106: BIM representation Building

8.3 Building Envelope

The present building was erected in 1900. The building style dates back to the Wilhelmina period. This era is characterized by the expansion of cities and the onset of industrialization, as well as the standardization of the building methods, nevertheless it is regionally coined. It is dominated by masonry buildings, in rural areas also half-timbered with masonry infill, often preserved design of street facades (stucco, sandstone, clinker) and wooden beam ceilings. Massive cellar ceilings and discontinuous heating via stoves in individual living rooms and wood/coal stoves in the kitchen are also common. In addition, the buildings are not equipped with hot running water or a bathroom. Toilets are found within the building, such as in the stairwell.

Renovation in the last decades has improved the situation, so nowadays central heating and decentral domestic hot water appliances in private bathroom may be found. In addition, recent renovation has added insulation on the roof of the building.

8.3.1 Vertical Walls

A typical characteristic of buildings erected in 1900 is the lack of thermal insulation on the walls. The walls are consisting of massive clay bricks. The exterior wall consists of solid brick masonry with a U-value of 1.7 W/(m²K) on average (decreasing from floor to floor). Furthermore, the thermal resistance is equal to 0.54 (m²K/W), while their solar radiation absorption coefficient is 0.5.

8.3.2 Roof

As common in historical buildings, the last ceiling towards the attic is made of massive thick wood (shaped wooden trunks). On top of that, there was a cold roof, and no Insulation. After renovation which took place in the last decade, part of those roofs is used for additional flats and insulation was added, both for the part between rafters and on top of the new flats. For the inclined part of the roof, the U-value shall be 0.165 W/(m²K), while for the flat part, it is considered as 0.161 W/(m²K).

8.3.3 Floors

8.3.3.1 Ground floor

There is a wood structure on top of a masonry arch (arched ceiling), which gives differing thermal characteristics, compared to the structures between ceiling and floor in the other storeys. The cellar's ceiling has been insulated, resulting in a U-value equal to 0.289 W/(m²K).

8.3.3.2 Floor Slabs

The structure separating the storeys consists of a wooden beam ceiling with a U-value of 0.8, having some mineral filling. Having heated flats, the structure separating storeys is adiabatic.

8.3.4 Fenestration

The fenestration in the apartments consists of double windows, with a U-value range from 2.5 to 2.7 W/(m²K). Several windows have been replaced with new ones that have come with PVC window frames and heat insulation glazing. In the staircase, single-glazing windows have been used that have a U-value equal to 5.1 W/ (m² K). Total energy transmittance of windows can be considered as 0.75, while no external shading is present.

Figure 107: Double windows

Table 29: Fenestration characteristics

Two-panel thermal insulation glazing	
U-valueW [W/(m²K)]	1.3
g-value [-]	0.75
g-correction [-]	0.90
Light transmittance [τD65-]	0.82
U-glazing [W/(m²K)]	1.10
Special glazing	No
Description	Wooden frames (composite windows, box-type windows...) (standard values with glass proportion 60% of window area)

8.4 Building Equipment

8.4.1 Sensors

One Legrand Netatmo Homecoach[2] multisensor has been installed in this Case Study and connected via the building's WLAN. This device measures:

- Temperature in °C
- Humidity in %
- CO_2 in ppm (optical measurements)
- Pressure in mbar
- Noise in dB

The device was placed in the corridor. Actual dashboard data from the Netatmo Apps can be retrieved, along with past measured data via API. Data is provided for every hour of the past day to ensure the acceptance of the apartments' residents.

[2] https://www.netatmo.com/en-eu/aircare/homecoach/specifications

8.4.1.1 Weather station

For the provision of weather data, official weather services operated by DWD for the region are available. In addition, the energy management system of the building provides information about the ambient temperature.

8.4.2 Meters

8.4.2.1 Electrical Energy

Electric energy supplied to the heat pumps is measured and can be retrieved. The electric energy demand of the tenants' private appliances is measured separately for all the flats and the acquisition was not possible.

8.4.2.2 Thermal Energy

Similarly to the electrical energy, thermal energy from the heat converters towards the building is measured and processed.

8.4.3 Systems

8.4.3.1 Heating

The building incorporates a mechanical ventilation and solar thermal system as shown in Figure 105. A buffer storage tank having a volume of 908 L is coupled to the heat pumps on the one side and to the solar thermal buffer tank on the other side, serving the heat release system for both building parts. The remaining energy is produced by a gas boiler with condensing effluent gas having a nominal heating power of 122 kW. The heat pumps extracting heat from exhaust and geothermal have a nominal heating power of 6 kW and 27 kW, respectively.

8.4.3.2 Ventilation

A mechanical ventilation system is installed, with heat recovery exploited via a heat pump.

8.4.3.3 Domestic Hot Water

The Domestic Hot Water is provided in each of the flats, based on electric power. Electric heaters are preinstalled or have been upgraded. The electric power consumption is included in the total private power demand of the flats, and as such is not known. The volume of the DHW storage varies between 50L and 120L, depending on the demand (head count). The heating power varies from 1.5 kW to 6 kW and power consumption is typically only observed during the night.

Typically, in the kitchens there is an additional smaller domestic hot water tank having a volume of 5 L and a maximum power of 1.5 kW. Those units are switched on during the whole day, providing a constant DHW temperature. However, some individual improvements may have been made in the recent past years.

Figure 108: Typical older DHW tank

8.4.3.4 Solar Thermal collector

The building features a solar thermal collector on the roof with an aperture of 42 m² and inclination of 40° oriented 16° towards the south-east. The thermal energy is stored in the buffer storage tank, which is also connected to the boiler and the heat pumps.

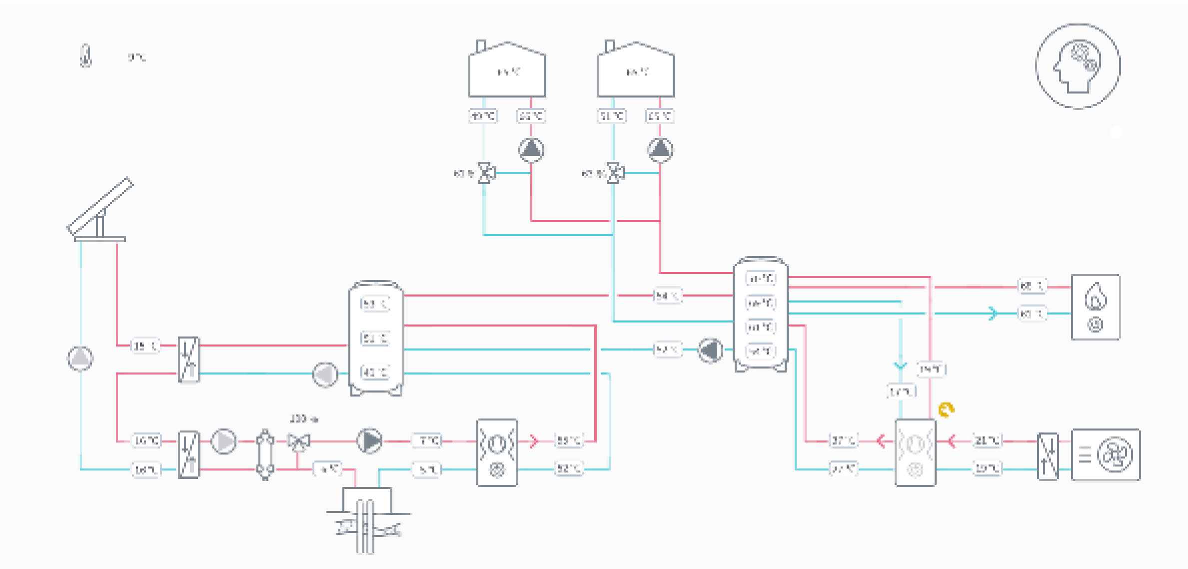


Figure 109: Solar Thermal Collector Installation

8.4.3.5 Building (Energy) Monitoring

The information about the total heating demand can be acquired from the energy monitoring tool, which is provided by an external party (GREEN FUSION start-up company) and also offers the possibility of AI-optimization. The system integrates information from power, heat and gas and allows an actual view into the energy flows of the central HVAC. It also shows the actual status of the valves and the temperatures in a HVAC plant diagram. There is yearly information about the individual energy demand in the apartments.

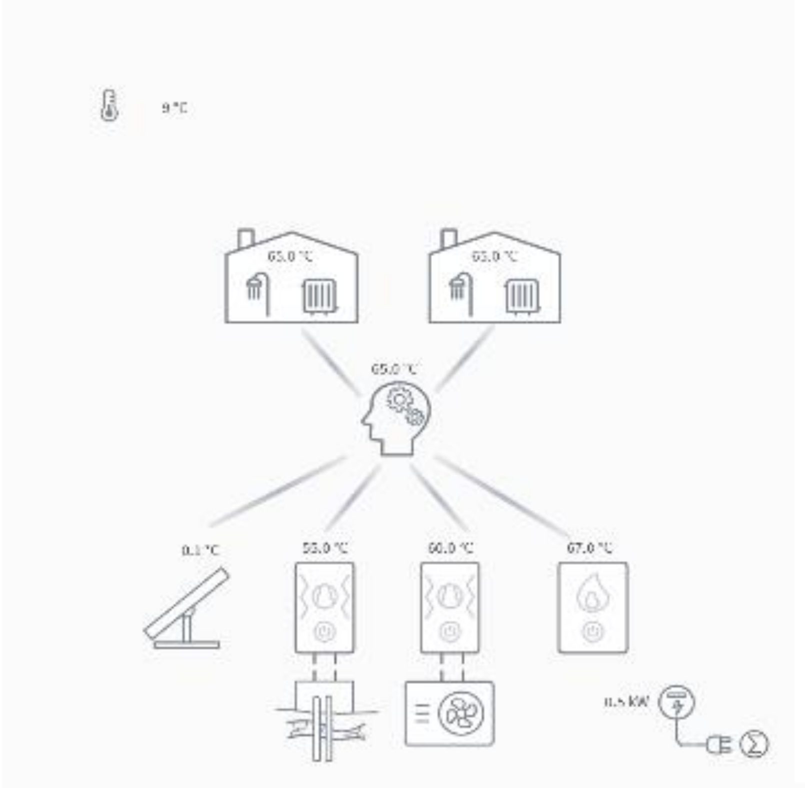


Figure 110: Overview of the Energy Monitoring System

The data acquisition process is shown in Figure 111 below.

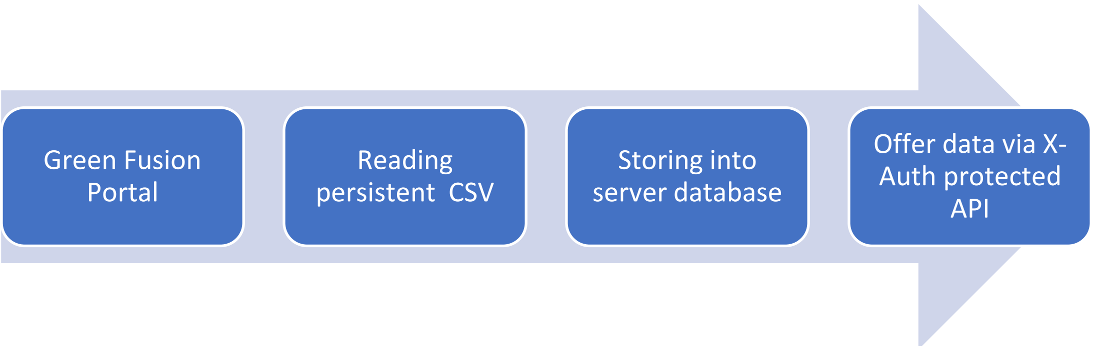


Figure 111 Overview of CS5 data acquisition system

8.5 Pre-pilot EPC assessment

The asset-based Energy certificate is based on data acquired during the modelling of the BIM. Following the national legislation, it was issued for the whole building. The Efficiency class, after the renovation, is A+. Since natural gas is used and electric power produced also via Gas and Coal, the Efficiency Class related to primary energy is worse.

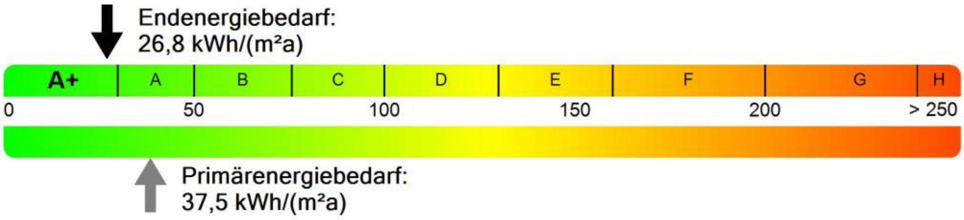


Figure 112: Recent (German) asset based EPC for the building

8.6 Pre-pilot SRI assessment

The results of the SRI assessment are displayed in Figure 113 below.

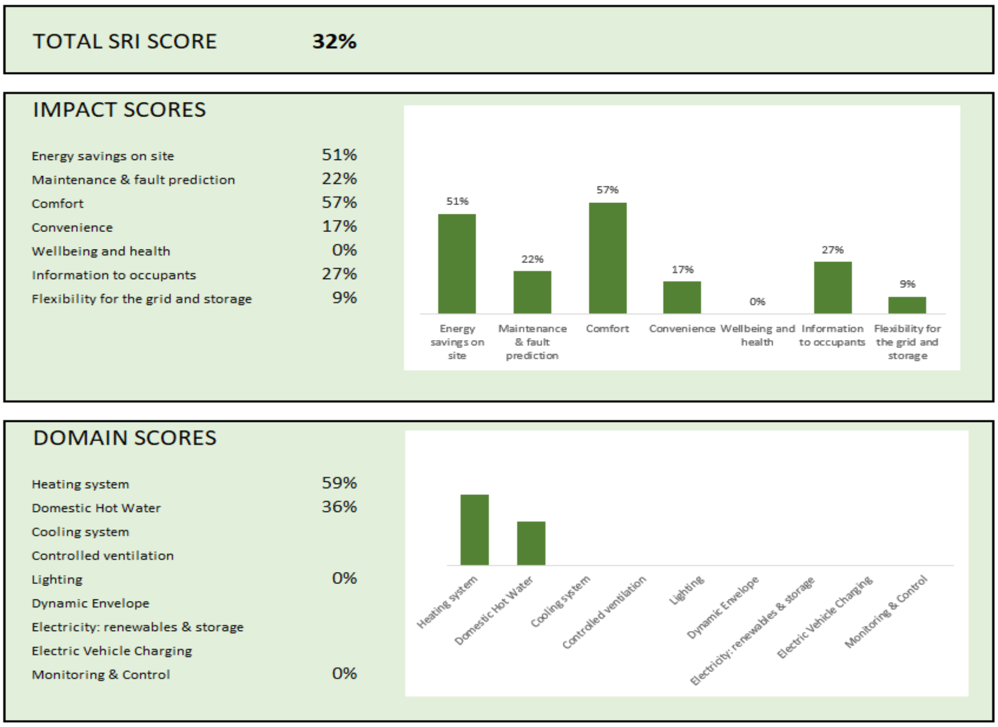


Figure 113: SRI assessment results

8.7 Scenarios Deployment

CS5 satisfied the prerequisites for applying the asset-based and operation-based EPC methodologies, as well as to test the majority of the considered UCs:

- *Complete BIM file delivery*: the building's IFC file was provided within the pilot's preparation period. Several modifications were applied to reach the minimum input requirements for appropriate parsing and issuing the asset-based EPC.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: IML access to the available indoor quality sensors and energy consumption meters through a dedicated API, was successfully established.
- *Provision of historical data*: The heat pump systems' electrical energy consumption, the gas consumption and data related to indoor quality and energy consumption were provided in addition to the option to access the API.

Figure 114 displays the digital twin of CS5, combining the BIM literacy with collected data. More information about the deployment prerequisites can be found in D5.8 “D^2EPC Pilots Demonstration v2”.

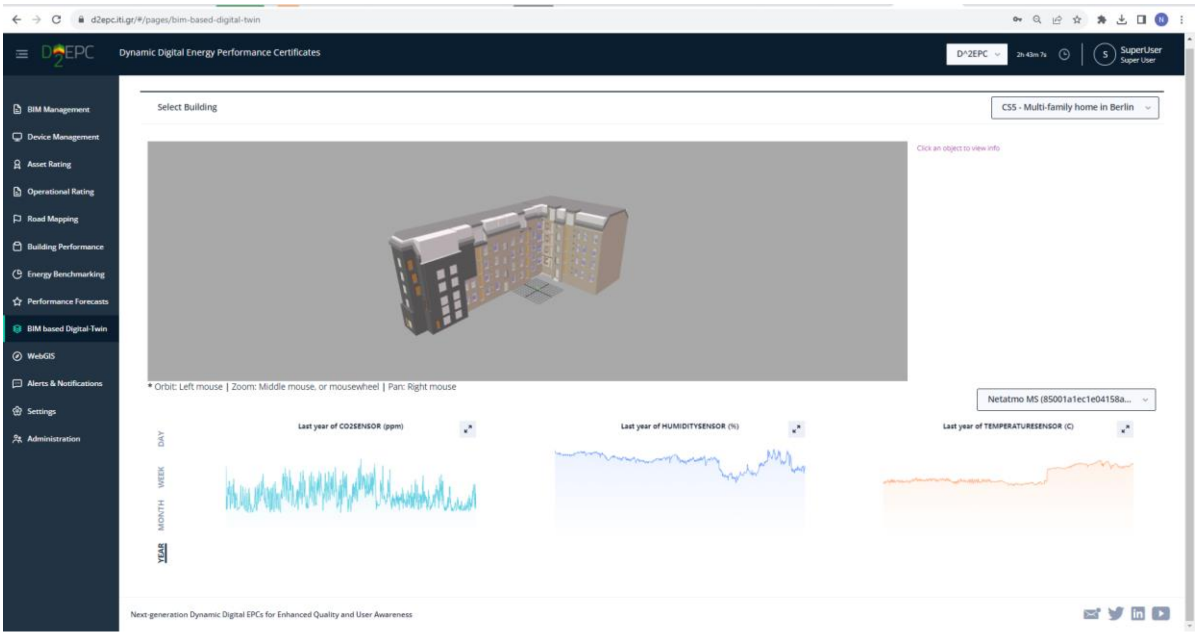


Figure 114 BIM-based Digital Twin of CS5

9 Case Study #6: Multi-family home in Berlin Germany

9.1 Objectives and Scope

This building is located in Neukoelln, Sonnenallee 159, in the center of Berlin. It is a historical building consisting of three parts with dominant residential usage. The building was constructed in 1918 with an overall building area 2231 m^2 and includes a total of 29 rented apartments. The façade towards the street has partly balconies and a central building ledge located behind a tree. The old box style windows consist of two separate windows with single glazing each, though most of them were exchanged by double glazed new windows with internal shading. District heating was installed in 1989 while there is no central infrastructure for cooling and ventilation.

9.2 Topology

The overall building consists of three connected components as shown in Figure 115.

Table 30: Zones of the building

Zone	Spaces
Stores	Business premises for sale.
Residential	Living room, Kitchen, Guest Room, WCs, Single Bedroom, Double Bedroom, Game Room, Bathroom, Halls- Staircase
Staircase	Unheated
Basement	Plenums (storage compartments), Central heating Room, unused laundry room

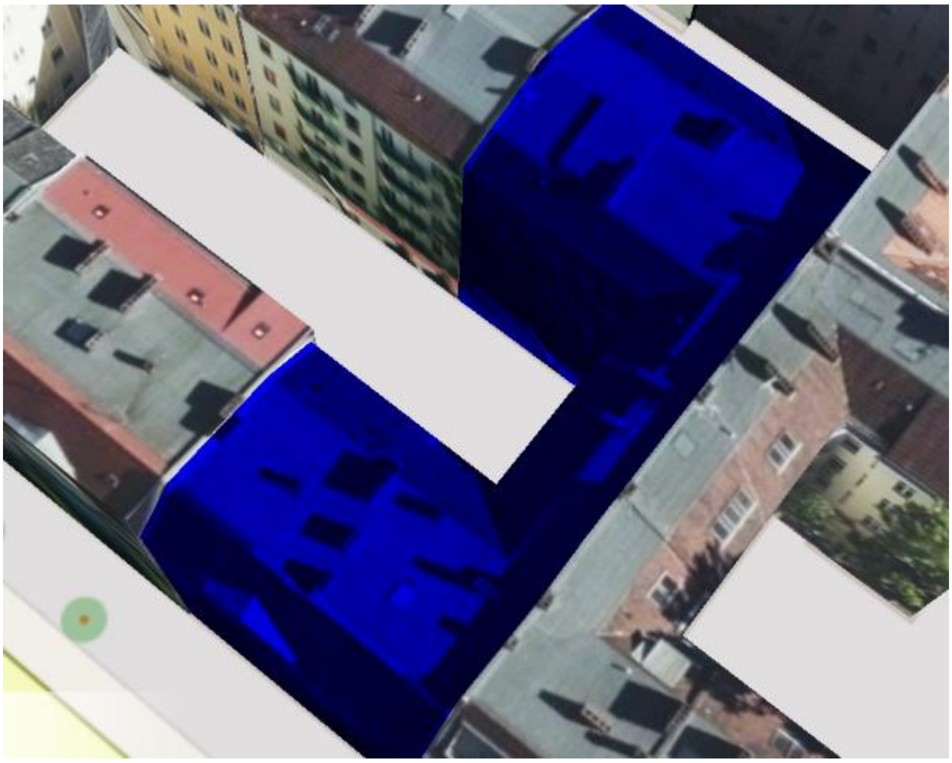


Figure 115: Building volume Pilot Study 6 Berlin

Figure 116: View from the street side and from the backyard Case Study 6

Figure 117: Window details

No original construction plans are available, though the following floor plans were drawn newly for a planned renovation. Since the building is now more than 100 years old, there were several undocumented modifications and there is no access to certified building element characteristics.

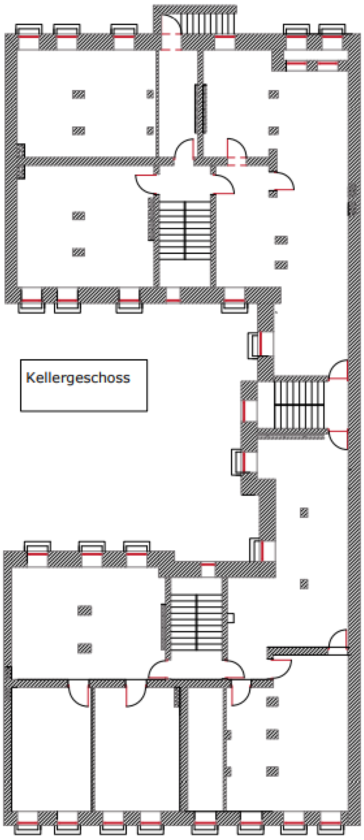


Figure 118: Basement

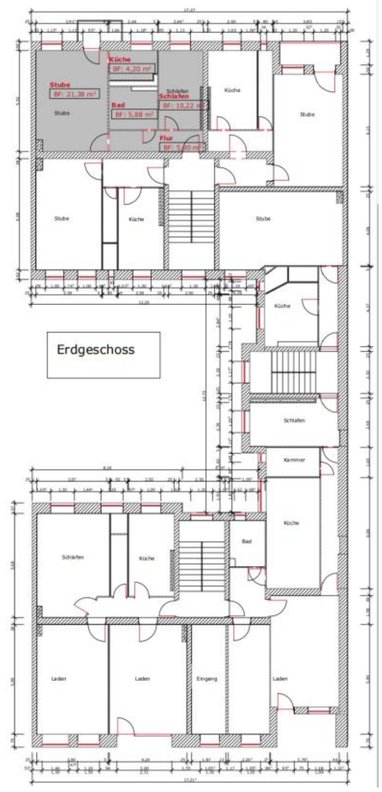


Figure 119: Ground floor

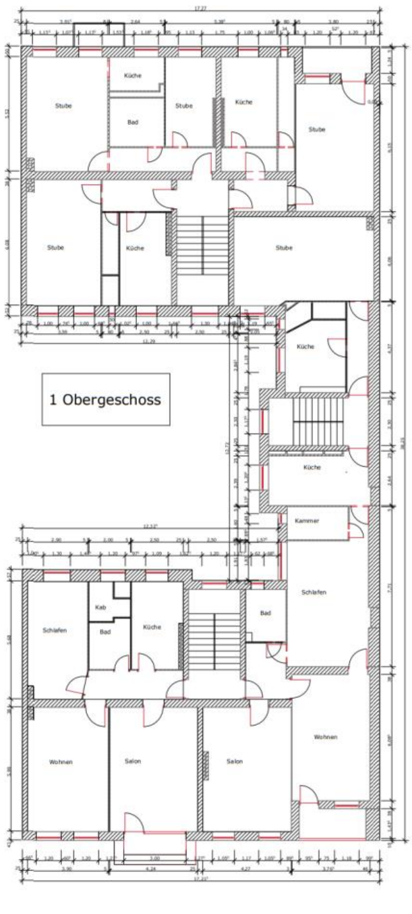


Figure 120: First floor

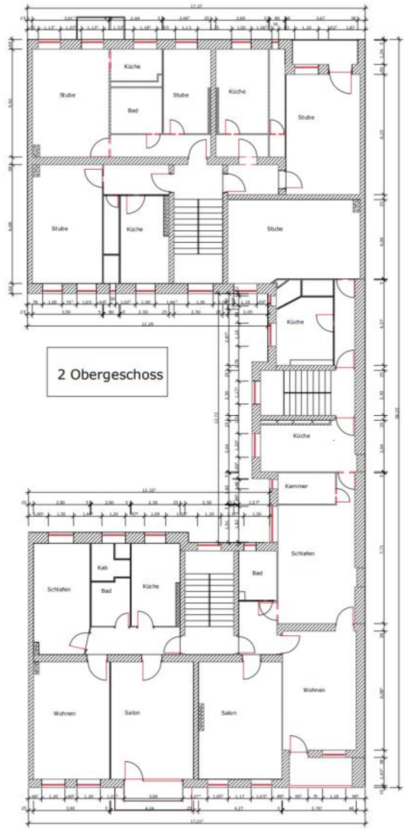


Figure 121: Second floor

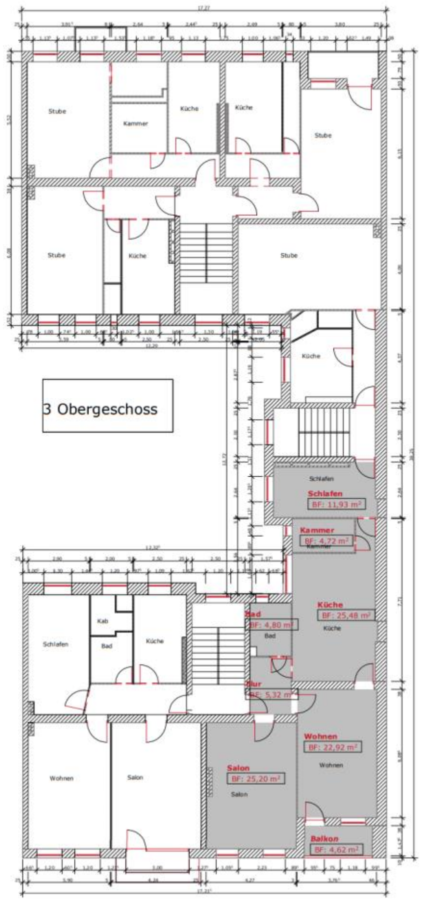


Figure 122: Third floor

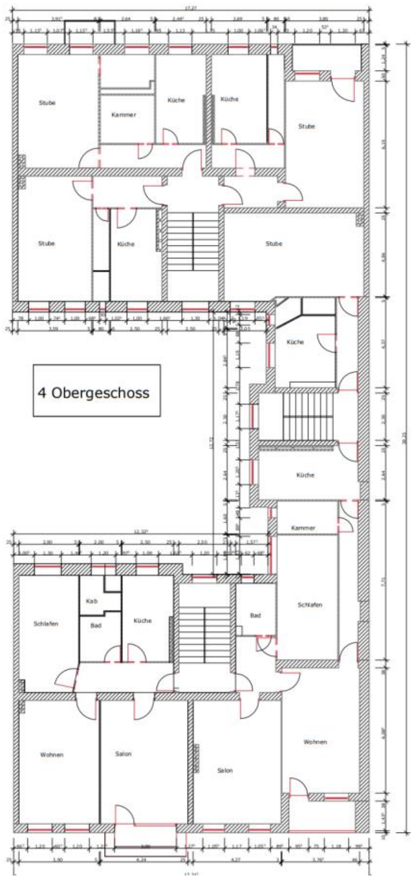


Figure 123: Fourth floor

9.3 Building Envelope

The building was erected in 1918. Characteristic for this building epoch is the increasing industrialization of building material production as well as the use of inexpensive and simple materials and material-saving constructions. Single- and double-shell masonry buildings, massive basement ceilings dominate in comparison to previous building styles. The use of building elements with air chambers improves thermal insulation. Heating is provided discontinuously by stoves or by coal central heating. In the kitchens, cooking is done with coal or gas stoves.

9.3.1 Vertical Walls

Typical with those ancient buildings, there is no thermal insulation. The walls are consisting of massive clay bricks, having one brick less for every storey. The last ceiling is made of massive thick wood. The exact thermal characteristic of the walls might be estimated better than for historical windows. The exterior wall consists of a solid brick masonry with a U-value of 1.7 W/(m²K) on average (1.2 W/(m²K) for 51 cm), decreasing from floor to floor. The building has better performance than deducted from that value, because of its massive storage capacity, levelling out temperature differences between day and night.

9.3.2 Roof

A typical brick masonry is found on top of the last wooden ceiling with a lambda value 1600 kg/m³. There is interior and exterior plaster (roughcast) with a thickness of 1.5 cm. This is common for construction during the Wilhelminian period. Wooden beam ceilings with clay or cinder fill are separating the floors. The bottom of the ceiling is boarded with wood, typical of Berlin tenements.

In the non-renovated building, there is a ventilated roof, without insulation. The top floor of Case Study 6 consists of a wood beam ceiling with visible balconies. The U-value of the ceiling may be assumed as 1 W/(m²K).

9.3.3 Floors

9.3.3.1 Lowest floor

The lowest floor towards the cellar consists of a wood structure on top of a masonry arch (arched ceiling).

9.3.3.2 Between floors

The layer consists of a wooden beam ceiling filed with mineral materials and covered with boards on the lower side and typically parquet floor on the upper side, in total having a U-value of 0.8 W/(m²K) (not relevant, as adiabatic).

9.3.4 Fenestration

Some box type double windows (windows with separated inner and outer wing) are remaining, typical for the era, with a span from 2.5 to 3.0 W/(m²K) for the U-value, also depending on the type of retrofitted, previously broken glass. More relevant is the maintenance status, since larger leakages may occur. For windows in historical buildings, the air flow is 1.5-3 m³/hm for 10 Pa differential pressure.

The windows were partially replaced by plastic windows, having special heat insulation glazing. Single glazing is seen in the windows of the staircases with an U-value of 5.1 W/(m² K). No geometrical shading is present apart from the neighbouring buildings and some vegetation.

Figure 124: Box double windows

Figure 125: Renewed PVC windows

9.4 Building Equipment

9.4.1 Sensors

Similar to Case Study 5, and as described in section 8.4.1, data acquisition devices namely the Netatmo Homecoach was proposed to building tenants for installation. In one flat they were accepted and data was acquired via wireless modem, providing a number of indoor conditions-related variables for a few months.

9.4.1.1 Weather station

Since there is no building energy management system, no temperature data recordings are available. For the needs of the project, an official weather service[3] for the region can be utilized.

9.4.2 Meters

9.4.2.1 Electrical Energy

Electrical energy is metered on apartment level and data not accessible because of raised privacy issues and the lack of a system architecture with the grid operators.

9.4.2.2 District Heating

Access to the existing heating demand meter (Figure 126) has been granted from the district heating service provider, though heat demand data may also be retrieved from the energy supplier (FHW-Neukölln), as data are being recorded and transferred every 15 minutes (i.e. consumption in kWh, power in kW, inflow and return temperature and the amount of water (m^3/h). An API has been made available for providing the aforementioned information, also including historical data.

[3] https://www.dwd.de/DE/leistungen/klimafaktoren/klimafaktoren.html

Figure 126: Heat meter

9.4.3 Systems

9.4.3.1 Heating

The heating energy is provided via district heating station. The control features weather-compensated flow temperature control.

The district heating network runs at 110°C/55°C, the heating system heating system at 70°C/55°C in the design case for an ambient temperature of -14 ° C.

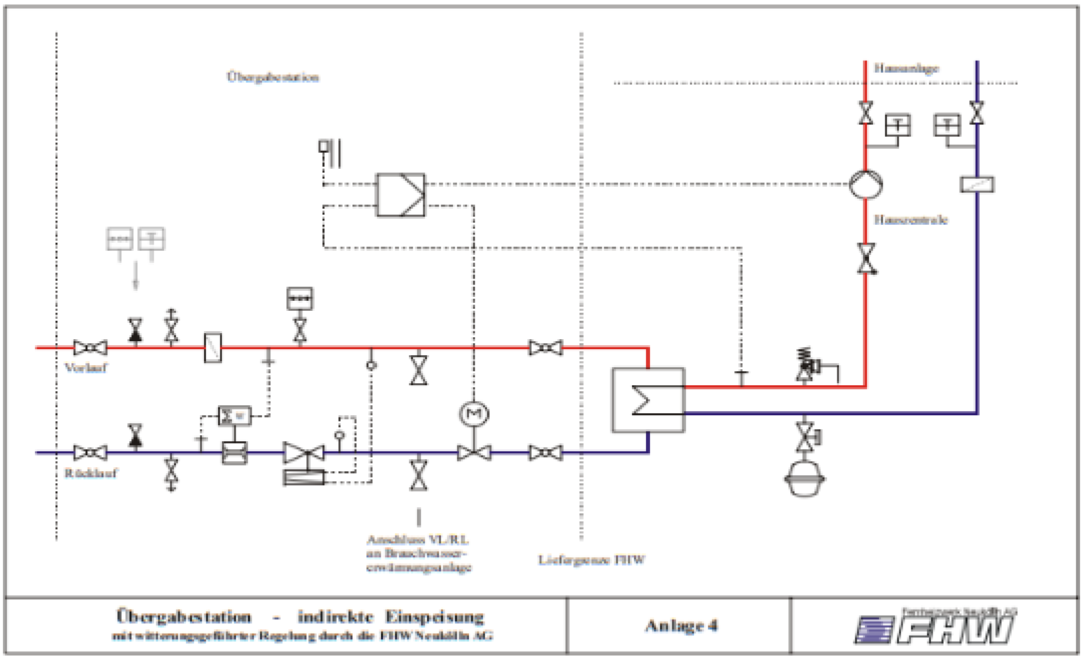


Figure 127: District Heating Transfer station scheme

Figure 128: District heating transfer station

9.4.3.2 Domestic Hot Water

Similar to section 8.4.3.3, decentral electric heaters under control of the tenants are being used for domestic hot water.

9.4.3.3 Building (Energy) Management

The heating energy is controlled via valves in the apartments. This is not integrated into a building energy management system.

9.5 Pre-pilot EPC assessment

An operational EPC is available for the building, as demonstrated in Figure 125 below. It is based on consumption for the period from 2012 to 2014 and shows an efficiency class of level D.

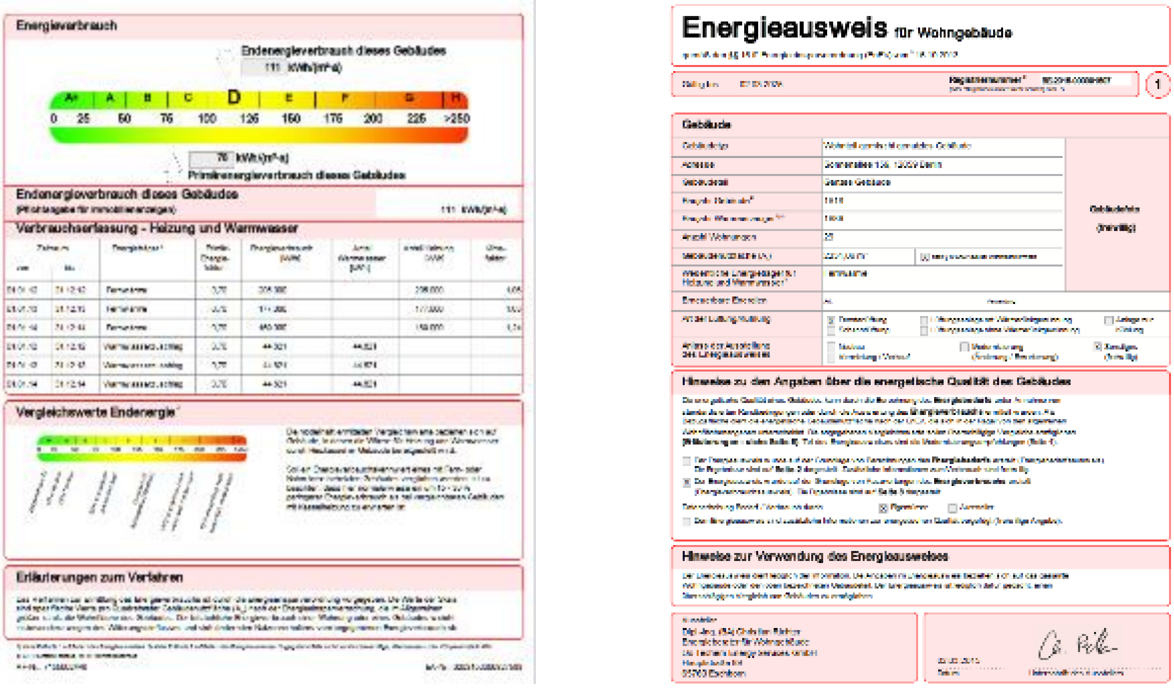


Figure 129: Energy consumption and certificate

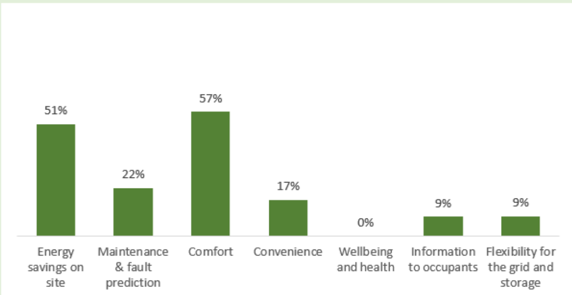
9.6 Pre-pilot SRI assessment

The results of the SRI assessment are displayed in Figure 128 below.

TOTAL SRI SCORE	31%

IMPACT SCORES

Energy savings on site	51%
Maintenance & fault prediction	22%
Comfort	57%
Convenience	17%
Wellbeing and health	0%
Information to occupants	9%
Flexibility for the grid and storage	9%



DOMAIN SCORES

Heating system	56%
Domestic Hot Water	36%
Cooling system	
Controlled ventilation	
Lighting	0%
Dynamic Envelope	
Electricity: renewables & storage	
Electric Vehicle Charging	
Monitoring & Control	0%

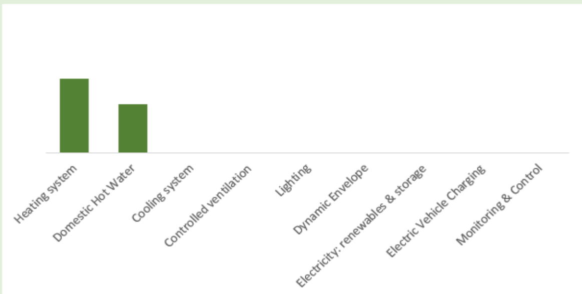


Figure 130: SRI assessment results

9.7 Scenarios Deployment

CS6 satisfied the prerequisites for applying the asset-based and operation-based EPC methodologies, as well as to test the majority of the considered UCs:

- *Complete BIM file delivery*: the building's IFC file was provided within the pilot's preparation period. Several modifications were applied to reach the minimum input requirements for appropriate parsing and issuing the asset-based EPC.
- *Integration of IoT sensor/meter data to the D^2EPC Platform*: IML access to the available thermal energy consumption meter, was successfully established.
- *Provision of historical data*: available historical data related to indoor quality and thermal energy consumption were provided.

Figure 131 displays the digital twin of CS6, combining the BIM literacy with collected data. More information about the deployment prerequisites can be found in D5.8 "D^2EPC Pilots Demonstration v2".

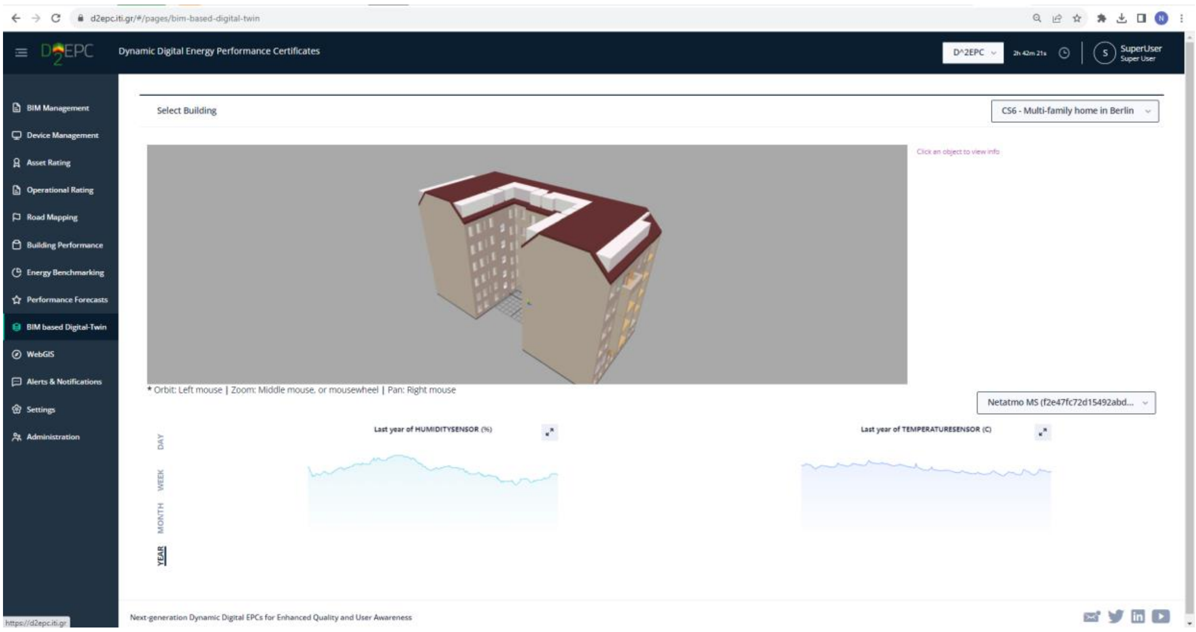


Figure 131 BIM-based Digital Twin of CS6

10 Case Studies Summary

10.1 Pilot preparation risks, issues and mitigation actions

Table 31 below presents the risks and mitigation actions that were identified prior to the case studies preparation phase and were documented in the previous version of this deliverable. Overall, there are three categories of risks: risks on IoT security, risks on technology, which mostly refer to hardware and connectivity issues - software issues are included in the category IoT security, and risks related to end-users.

Table 31: Risks and mitigation actions

ID	Risk	Description	Mitigation measures
	Risks on IoT Security		
1	Software vulnerabilities	Vulnerabilities such as bugs that affect the functionality of devices/ IoT platform in a way that was not intended.	• Regular and necessary updates for protection against vulnerability conducted by the third parties involved, e.g. data processors and IT personnel. • Request immediate notification and action in case of software bugs threats This kind of risk cannot be avoided completely.
2	Insufficient privacy protection	Lack of sufficient data protection, e.g. encryption when transferring or storing sensitive data/data collected from IoT devices.	• Encrypt commands and surveil command integrity. • Encrypt sensitive user data collected by IoT devices. • Ensure encryption is complete and correct configured. • Implement data protection policies and ensure GDPR compliance by means of letters of consent from end-users and data processing agreements. See also the risk of “End-users withdrawal”.
3	Insecure data transfer and storage	This is the risk of a breach or compromised data for example due to the lack of encryption and access controls before data is entered into the IoT ecosystem. This is a potential risk to take into account.	• Implement proper and secure authentication with individual device identification. • Encrypt data transfers within the network - see “Insufficient privacy protection”

			These measures should be discussed and implemented together with the technical partners from D^2EPC.
4	Server maintenance	Risk that hardware components break, system overload, cyber attacks	• Have a dedicated person that conducts routine preventive maintenance and data backups • Conduct regular server checks such as the need for installing updates/upgrades regularly
5	Access control	Unauthorized access of data and programs	• Restricting access to what is needed based on pre-established permissions • Specifying access rights or privileges to users
	Risks on technology (Hardware, Connectivity)		
6	Devices flaws - malfunction	IoT devices do not perform as expected, they arrive with flaws or broken.	• Conduct, when possible, devices tests and checks prior to purchase. This risk cannot be completely avoided.
7	Connectivity interference	Connectivity is off from time to time	• Conduct, when possible, connectivity tests and checks prior to the purchase of IoT devices. However, there is no guarantee how the device performs in this regard as interference might be related to the service provider and not the device itself. • Check for signal coverage prior to the acquisition of devices • Make sure that data is stored (either by the device itself or a datalogger) to avoid data losses. • Conduct regularly data retrievals for the periods in which connectivity was affected.

8	Poor installation of devices/ insufficient physical security	Lack of manual instructions for installation. Installers did not follow manual instructions and recommendations for proper functioning. Free open physical access to IoT devices.	• Provide installers with relevant information such as device manual with instructions as provided by the vendor. • Ensure/monitor adequate placement of devices according to the requirements by the vendor and secure access. • Hire qualified installers that have the permission and qualification to conduct such tasks in a timely and professional manner.
9	Delay of purchase, testing and installation	Delays, which can be triggered to a certain extent by the effects of Covid-19, i.e. shortage of products as well as lack of capacity by companies to provide dedicated support.	• Developing good and regular contact with vendors (suppliers). • Planning of activities with enough time in advance. This risk cannot be mitigated completely as implies dealing with third parties (e.g. vendors and installers).
10	Data cannot be used by the project	Data collected does not meet the needs of the project.	• Discussing in detail with partners on the scope and type of data that should be retrieved (format, measuring intervals, interfaces and data transfer methods) - D1.4 and T5.1 deal with the validation and assessment methodology
11	Lack of compatibility with D^2EPC platform	Difficulties in terms of data collection and integration from different IoT devices to the D^2EPC platform	T4.3 (energy performance verification and credibility) aims to secure the adequacy and operational status of all data collection infrastructure and identify any restrictions that might arise from the online data fusion, analysis and processing.[4]
	Risks related to end-users		
12	Lack of consent	End-users do not give their consent to conduct certain activities, e.g. installation of	• Provide end-users with clear information about the project goals and expected

[4] See risk assessment of the project.

		devices and/or collection of information.	benefits from participation/cooperation. • Explain end-users that participation is voluntary and that privacy issues are not compromised - GDPR compliance. • Fluent and regular communication with stakeholders.
13	End-users withdrawal	Early withdrawal or cessation of participation in the project.	• Make end-users feel comfortable with the project activities. • Maintain transparency of information.
14	End-users do not feel comfortable with the collection of information	Lack of willingness to participate in activities such as surveys (questionnaires).	• Translate questionnaires to their language for better understanding. • Avoid long and too complicated questions and the use of technical words. • Explain how such activities help with the development of the project and its overall goals.
15	End-users preference is not to have installed IoT devices that are perceived as highly intrusive	Lack of cooperation for installation of IoT devices	• Provide detail explanation of what kind of devices need to be installed, for what purpose and in which way such installation contributes to the development and goals of the project.

Following the completion of the case studies preparation, the issues that emerged and the corresponding applied countermeasures were documented and presented in Table 32 below.

Table 32: Pilot preparation issues & countermeasures

Issue	Description	Considered countermeasures	Result	Related risk(s)
Historical energy consumption values not complete for CS2 & CS3.	Electrical and thermal energy consumption prior to the initiation of data recording was available only as single-year total values for CS2 & CS3, which would cause problems in the issuance of the as-operated EPC.	Single-year values were spanned over 12 corresponding monthly values based on predefined assumption, though maintaining the same total energy consumption	The historical data provided were processed normally and the as-operated EPCs for CS2 & CS3 were issued successfully.	10
BIM files deficiencies	Missing or wrong information identified in the BIM files during post-processing by the D^2EPC tools	BIM files were corrected by CERTH in communication with the pilot responsible partners. The validation mechanisms of the Web Platform and the integrated tools were improved to handle missing/wrong information more efficiently	The BIM files were correctly processed, allowing the D^2EPC tools to produce results.	1, 10
Electrical energy consumption not available for CS5 & CS6	Electrical energy data were difficult to be acquired for Case Studies CS5 & CS6	Operational rating indicators related only to heating and cooling were calculated.	The as-operated EPC was issued considering the available energy uses.	-

11 Conclusions

The second version of the deliverable related to pilot planning and setup aimed to provide the fully detailed overview of the D^2EPC pilot sites and described the followed course of action towards preparing them for the implementation of the business scenarios and corresponding use cases in T5.3.

The building's topology, enclosing envelope and underlying equipment were described to the highest level of detail possible for each pilot site, providing updates in relation to the previous report version. An assessment of the current EPC rating as well as of the current SRI score was provided, acting as benchmarking for the implementation of the D^2EPC methodology and the comparison with the acquired results. The expected scenarios deployment was provided for each case study as well.

Finally, this document outlined the different issues that roused during the case studies preparation phase, along with the measures taken to overcome them. To this end, it covered all the aspects towards ensuring the smooth undertaking by the activities of T5.3 and the successful demonstration of the D^2EPC solution.