# Supplement S2: Operational Manual of the BEST Tool




This study represents an advancement of the research previously conducted by CITERA, the research center of Sapienza University of Rome, within the framework of the "Electricity System Research" program in collaboration with ENEA and the Ministry of Economic Development. Earlier research focused on the development of solutions and tools to enhance the energy efficiency of buildings at a territorial scale.

In the prior phase of the project, a series of key methodological steps were followed:

1. **Identification and classification of building types**: A comprehensive mapping of the national residential building stock was conducted, with particular emphasis on categorizing the main types of upper horizontal closures (UHCs) and opaque vertical walls based on their construction period. This phase culminated in the development of a structural matrix summarizing the primary characteristics of these elements.
2. **Analysis of insulating materials:** The most commonly available insulating materials were analyzed, selected according to environmental sustainability and energy efficiency criteria. This analysis identified a wide range of sustainable insulation solutions, with a particular focus on off-site approaches that promote industrialization and prefabrication.
3. **Energy performance simulations:** Simulations were carried out to identify the most effective insulation solutions for different types of horizontal and vertical closures. These analyses evaluated the energy and environmental performance of each material or system, defining the most efficient combinations.
4. **Definition of standardized solutions:** Based on the simulation results, optimized and standardized solutions were developed for each type of existing building element. An abacus of solutions was created, complemented by detailed technical sheets for each combination of closure and insulation. These sheets provided information on technical specifications, energy performance, and the economic benefits of each solution.
5. **Development of a decision-support matrix:** The standardized solutions were integrated into a matrix designed to guide professionals in selecting the most appropriate solutions based on energy and sustainability criteria. This tool facilitates the identification of efficient prefabricated interventions tailored to specific building scenarios.
6. **Creation of the BEST (Building Energy Saving Tool):** The earlier research laid the groundwork for the development of BEST, an innovative tool enabling preliminary energy assessments and assisting designers in selecting optimal retrofit solutions. BEST incorporates information from the matrix and the abacus, allowing users to identify existing building types based on construction period, building typology, and climate zone. It supports the selection of standardized solutions, preliminary energy analyses, energy and cost-saving simulations, and provides access to detailed technical sheets for the proposed solutions.

# TABLE OF CONTENTS

**Abstract** 3

**1. Building data** 3

1.1. General data: user profile and location 3

**2. Architectural characteristics** 4

2.1. Building characteristics 4

2.2. Building characteristics_Building geometry and orientation 5

2.3. Building characteristics_Building boundaries 6

2.4. Building characteristics_Windows 7

2.5. Envelope description 7

**3. Interventions** 10

3.1. Applicable thermal insulation solutions 10

**4. Systems and usage** 12

4.1. Building use 12

4.2. Heating system 14

4.3. Cooling System 16

4.4. Domestic hot water (DHW) system 18

4.5. Solar thermal system (for hot water) 19

4.6. Photovoltaic solar system (for electricity) 21

**5. Economic and energy indicators** 22

**6. Procedure for the control and management of errors in the compiled data** 22

**7. Calculation start** 23

**8. Results** 24

## Abstract

The proposed tool aims to improve the energy efficiency of the national residential building stock in line with the energy transition outlined by current regulations. BEST facilitates the identification of the most suitable renovation solutions for designers, considering the building's construction period, architectural type, and climatic zone. Based on an Excel calculation engine with Visual Basic macros, the tool integrates pre-calculated solution data through a dynamic matrix featuring 718 configurations, adhering to the parameters defined by the current regulations. Through a database of optimized solutions, the system enables the selection of standardized, efficient, and sustainable technologies that meet the performance requirements established by current regulations for winter building construction, in reference to Off-Site practices.

The tool provides an energy pre-analysis that allows users to evaluate the impact of renovation interventions on the building's opaque envelope, offering guidance on energy and economic savings. Performance simulations enable professionals to compare various optimized solutions, supported by a dynamic matrix that combines criteria related to the existing building envelope and regulations. The calculations include energy needs for heating and cooling, considering both the envelope and the most common building systems.

A distinctive feature of the tool is its ability to select vertical and horizontal closures based on specific criteria, thus reducing the complexity related to describing stratigraphies. The proposed efficiency solutions, tailored for each case, allow the calculation of economic savings, net present value (NPV), and available incentives. Additionally, users can download detailed reports with stratigraphy, simulation results, thermo-hygrometric checks, and sustainability indicators.

The tool allows users to:

1. Create a pre-intervention energy model of the building;
2. Evaluate current energy performance through synthetic indicators;
3. Select optimized renovation solutions based on consolidated data;
4. Build a post-intervention model and analyze the economic and technical benefits;
5. Compare different solutions to define intervention priorities.

## 1. Building data

*1.1. General data: user profile and location*

The general data section includes information on the user and the building's location. In this subsection, the province and municipality can be selected from a dropdown menu, which is essential for automatically determining the degree days and corresponding climate zone.

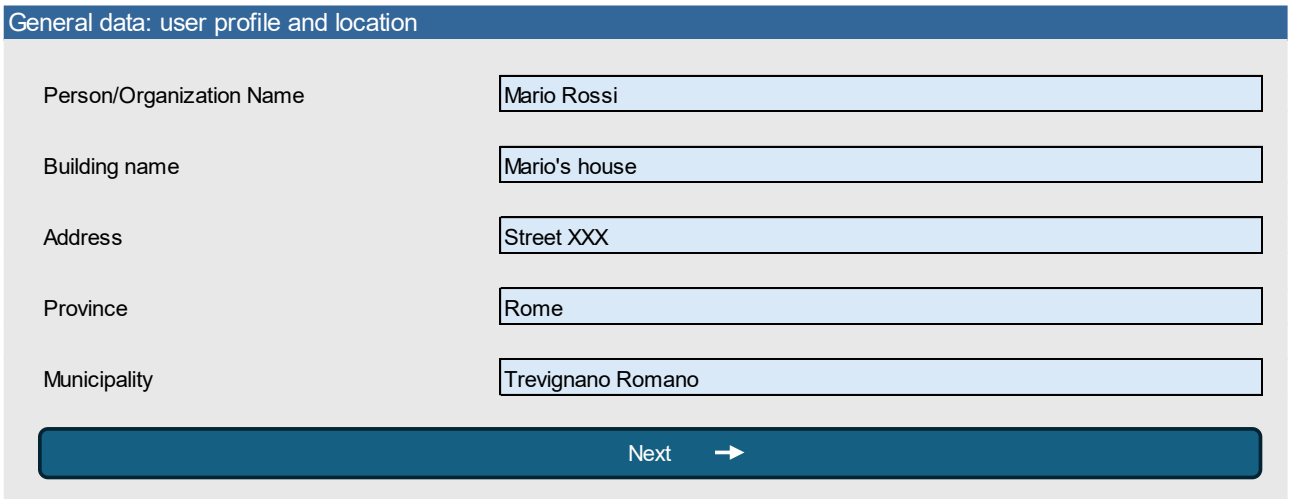



**Figure 1 .** Screenshot of the BEST tool displaying the subsection “General Data: user profile and location” inside the section “Building data” with the case study data used for the analysis.

## 2. Architectural characteristics

*2.1. Building characteristics*

The construction period is required to identify the most common building envelope typologies. The characterization of the building, essential for the calculation of energy demands, is based on a set of general information describing its subdivision and dimensions. The intended use of the building can be selected from two options:

- E.1(1) – Residential buildings with continuous occupancy (dwellings, boarding schools, convents, penitentiaries, barracks);
- E.1(2) – Residential buildings with intermittent occupancy (vacation homes and similar structures).

The shading context is categorized into four options:

- Surrounding elements with significantly greater height (high-density city center);
- Surrounding elements with greater height (medium-density city center);
- Surrounding elements of similar height (suburban area);
- Surrounding elements with lower height (detached building with no surrounding obstructions or shading elements).

The "Building Characteristics" subsection includes also the following data:

- **Number of floors analyzed**: In the case of a standalone building, the total number of floors must be specified. If the assessment concerns only a portion of the building, only the relevant floors should be considered. It is important to note that this value must match the total number of floors only if the entire building is included in the analysis. If certain floors (e.g., garages, basements, or unconditioned attics) are excluded, only the floors under evaluation should be indicated.
- **Number of housing units analyzed**: For residential buildings, this value corresponds to the number of apartments.
- **Average net floor-to-floor height**: This refers to the net floor height, excluding the thickness of slabs.
- **Total useful floor area (all floors):** This represents the usable net floor area across all levels. This field is editable, and to facilitate data entry, the system suggests an estimated value based on previously entered information.

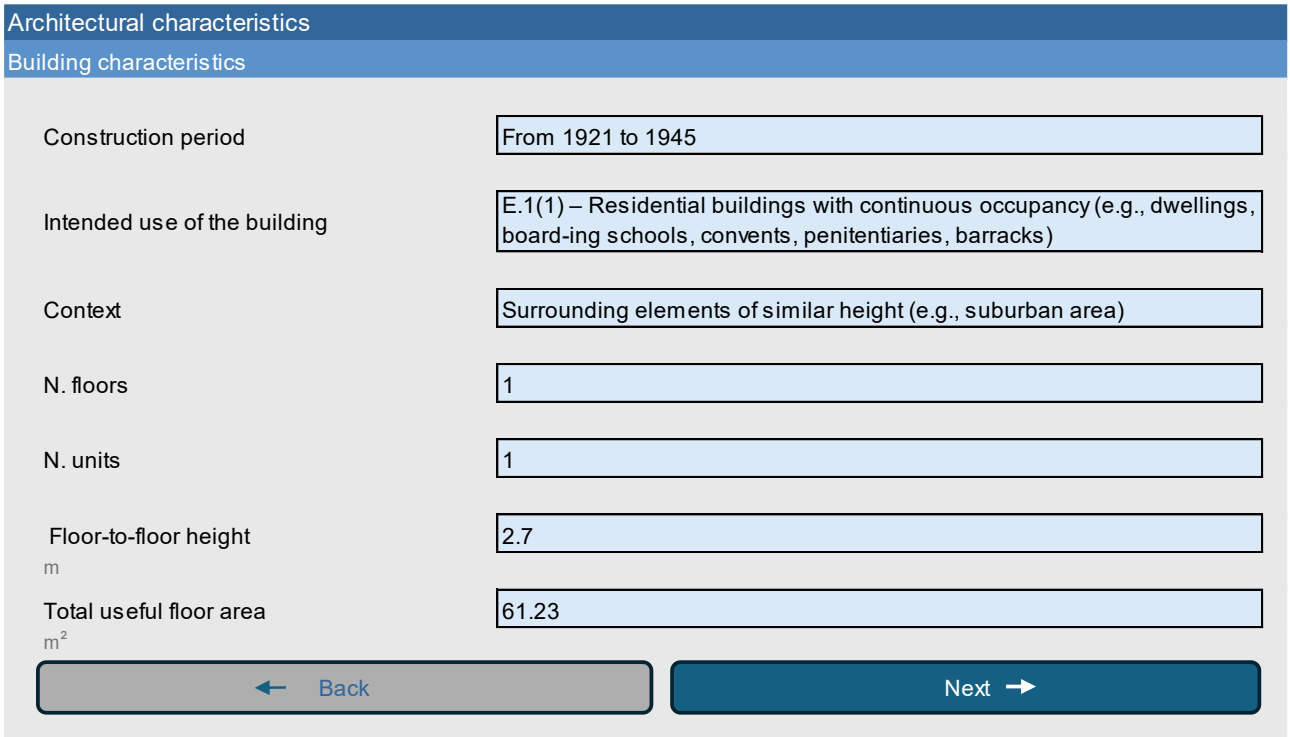



**Figure 2.** Screenshot of the BEST tool displaying the subsection "Building characteristics" inside the section "Architectural characteristics" with the case study data used for the analysis.

*2.2. Building characteristics_Building geometry and orientation*

The second subsection under "Architectural Characteristics" pertains to the description of the building envelope, including the following information:

- **Climate zone:** The classification of the climate zone is based on the geographic location of the building as specified in the "Building Characteristics" section.
- **Building floor plan shape**: The most appropriate typology is selected based on the reference diagram. The floor plan can be:
  - Rectangular or square;
  - L-shaped;
  - Double L-shaped;
  - Courtyard-type.
- **North orientation**: The building's orientation is specified in degrees based on the reference diagram.
- **Wall length (m):** The length of each wall (side A, side B, side C, side D, side E, side F, side X, and/or side Y) is indicated, measured from end to end, including the thickness of internal partitions but excluding the thickness of external walls. If lengths vary across floors, an average value should be provided.

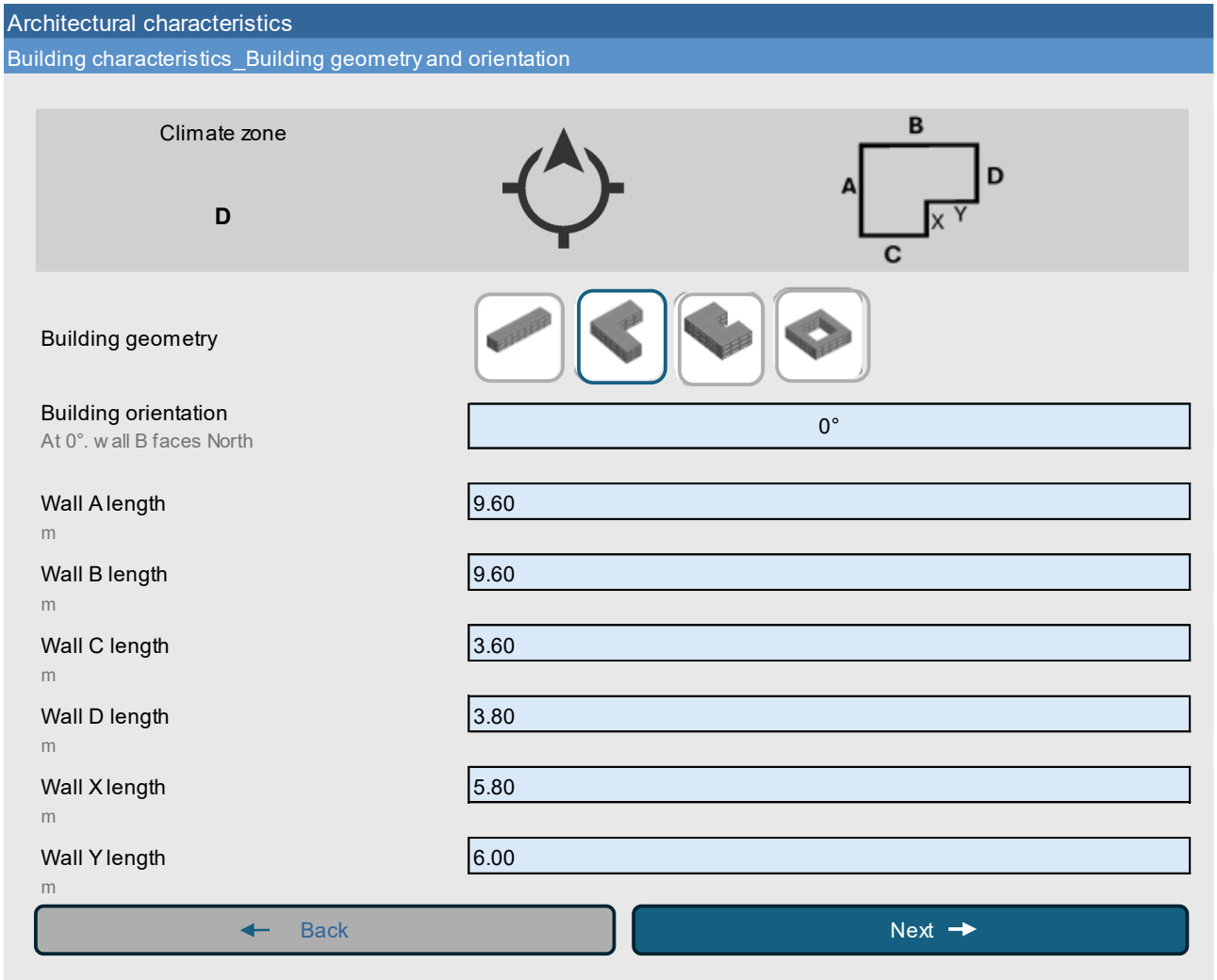



**Figure 3.** Screenshot of the BEST tool displaying the subsection "Building characteristics_Building geometry and orientation" inside the section "Architectural characteristics" with the case study data used for the analysis.

*2.3. Building characteristics_Building boundaries*

The third subsection under "Architectural Characteristics" contains:

- **Boundary conditions**: The adjacent environment on the opposite side of the wall is identified. Possible conditions include:
  - **External:** Represents exposure to outdoor air;
  - **Another apartment:** Refers to adjacent heated/cooled spaces, even if they are not designated as residential units;
  - **Unheated space:** Includes unconditioned areas such as stairwells, garages, elevators, cellars, etc;
  - **Ground:** Indicates contact with the ground.
- **Upper boundary condition (elements above the ceiling):** Specifies what is located above the ceiling of the analyzed space. Possible conditions include:
  - **External:** Represents exposure to outdoor air;
  - **Another apartment:** Refers to adjacent heated/cooled spaces, even if they are not designated as residential units;
  - **Unheated space:** Includes unconditioned areas such as stairwells, garages, elevators, cellars, etc;
- **Lower boundary condition (elements below the floor):** Specifies what is located below the floor of the analyzed space. Possible conditions include:
  - **External:** Represents exposure to outdoor air;
  - **Another apartment:** Refers to adjacent heated/cooled spaces, even if they are not designated as residential units;
  - **Unheated space:** Includes unconditioned areas such as stairwells, garages, elevators, cellars, etc.

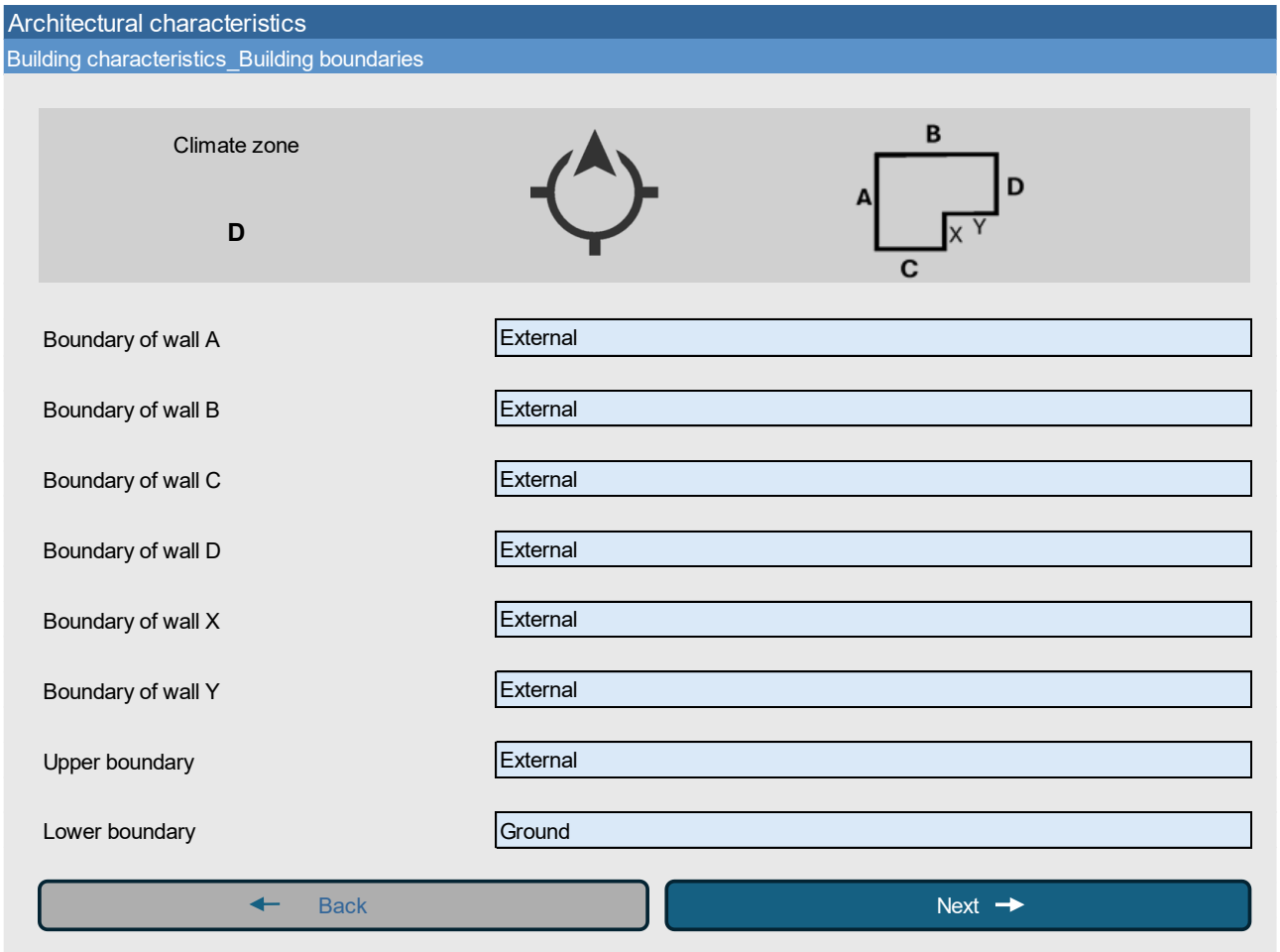



**Figure 4.** Screenshot of the BEST tool displaying the subsection "Building characteristics_Building boundaries" inside the section "Architectural characteristics" with the case study data used for the analysis.

*2.4. Building characteristics_Windows*

In the fourth subsection, the type of frame and glazing, along with their surface area, is selected from a drop-down menu:

- **Window type**: Specifies the type of window frames, categorized as follows:
  - Single glazing | metal frame;
  - Single glazing | wooden frame;
  - Single glazing | PVC frame;
  - Double glazing | metal frame;
  - Double glazing | wooden frame;
  - Double glazing | PVC frame
- **Glazing surface area**: This specifies the total glazed surface area of the corresponding wall in square meters.

This structured approach ensures that all relevant building characteristics are systematically recorded, facilitating accurate energy performance assessments.

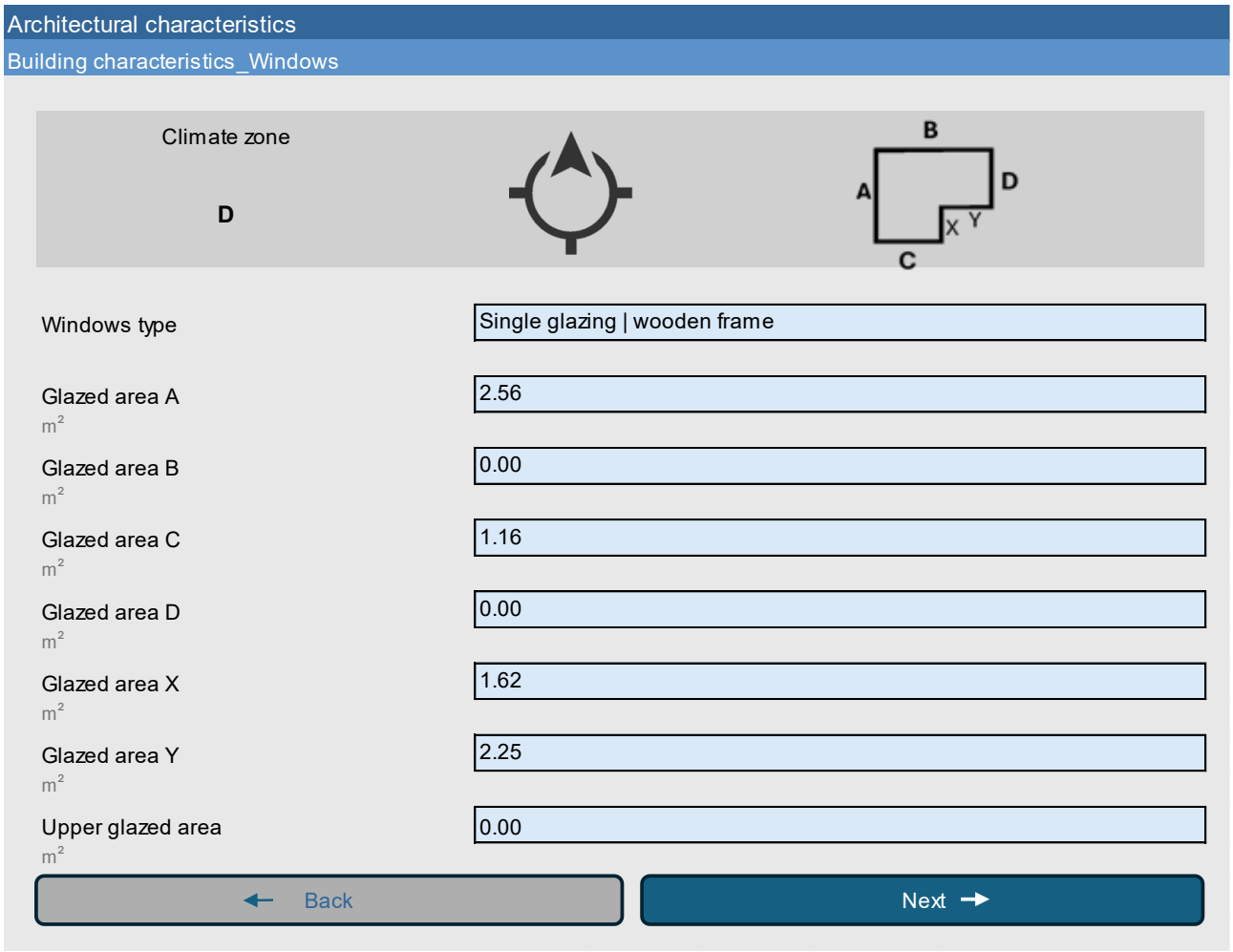



**Figure 5.** Screenshot of the BEST tool displaying the subsection "Building characteristics_Windows" inside the section "Architectural characteristics" with the case study data used for the analysis.

*2.5. Envelope description*

Within this subsection, the user can define all information related to the building envelope:

- **Construction period:** The time period during which the building under analysis was constructed. This information is necessary to suggest the most appropriate construction types for the building envelope.
- **Building type:** Two main categories of residential buildings are identified:

    - Isolated building: This category typically includes residential structures located on the periphery of urban contexts, often outside historic city centers, and generally accompanied by a private green area of varying size. It is further subdivided into:
        - Single-family;
        - Multi-family.
    - **Multi-family building:** This category includes multiple independent residential units aggregated into a single multi-story structure, typically sharing a common entrance and stairwell serving multiple units per floor. It is further classified into:
        - In-line;
        - Tower;
        - Row;
        - With balcony;
        - Gallery;
        - Block.
- **Construction type:** The main construction systems available for selection are based on the classification provided in the Italian Law of February 2, 1974, No. 64, *"Measures for constructions with specific provisions for seismic zones,"* Article 54, which lists them as follows:
    - **Load-bearing masonry:**
        - Stone;
        - Stone and brick;
        - Brick;
        - Concrete.
    - **Frame structures:**
        - Wood;
        - Reinforced concrete.

Subsequently, the characteristics of the upper horizontal closure (roof) are defined, specifically:

- **Morphological features:** The morphological classification is based on the type of waterproofing layer, which determines two subcategories:
    - **Continuous roofing:** in which the waterproofing layer ensures water tightness regardless of the slope of the upper closure surface;
    - **Discontinuous roofing:** in which the layer (such as tiles, slabs, or shingles) ensures water tightness only at specific slope values, known as "pitched roofs."
- **Geometric features:** From a geometric perspective, roofs are classified based on slope, as follows:
    - **Flat horizontal:** slope <1%;
    - **Sub-horizontal:** slope between 1–5%;
    - **Inclined flat:** slope >5%;
    - **Curved**: with regular or irregular shape.
- **Accessibility: Roofs** are also differentiated by level of accessibility, determined by the type of functional layers:
    - **A – B:** non-accessible, except for maintenance of the roof or installed systems;
    - **C – D – E:** walkable or drivable;
    - **F:** green roofs (roof gardens).

After completing all information regarding the building envelope, the tool provides a list of existing roof types, existing opaque wall types, and existing lower horizontal closure types, from which the user can select those that most closely resemble their actual building. The pre-retrofit structure code is determined either through user selection or derived from the dynamic matrix.

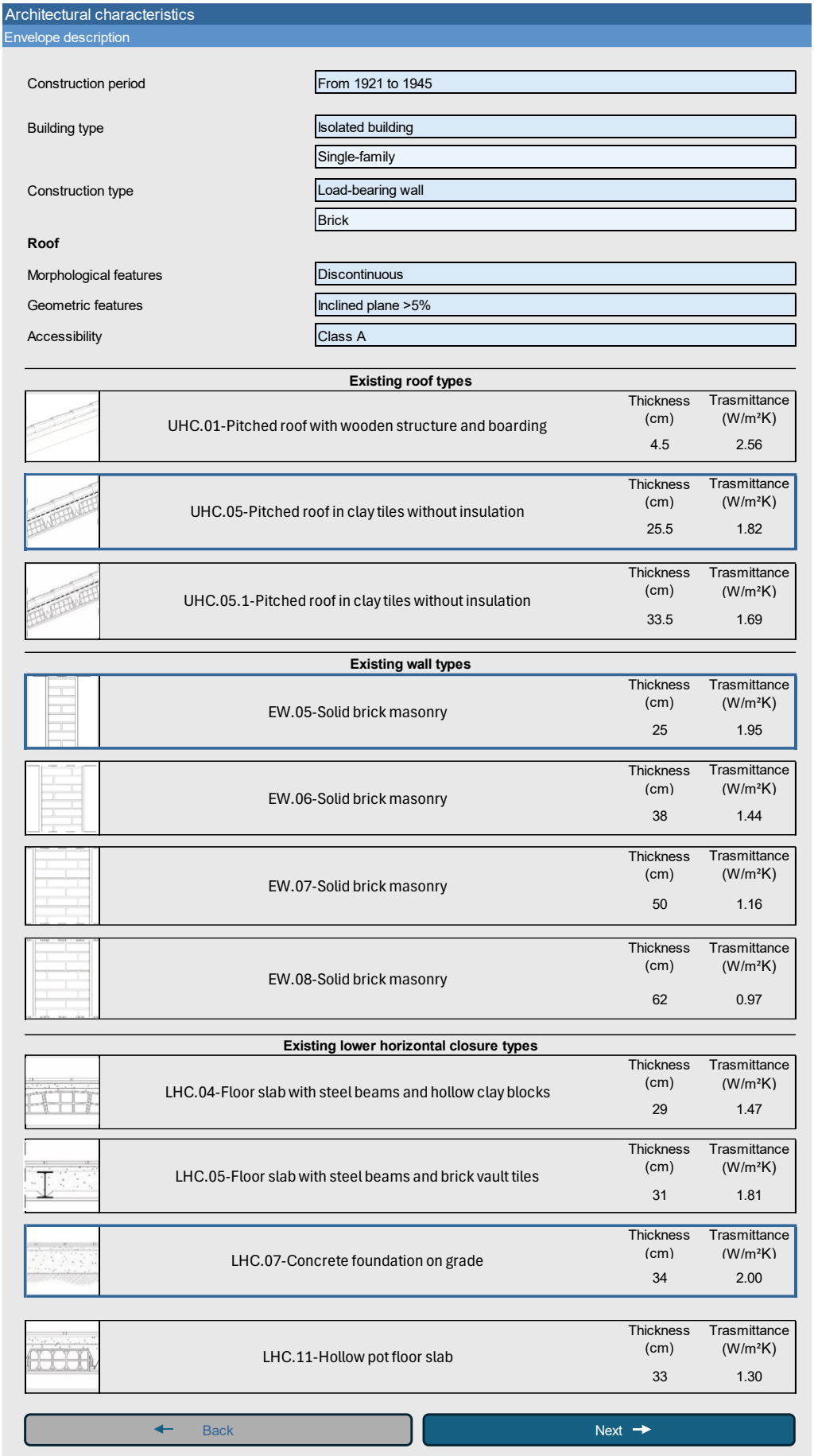



**Figure 6.** Screenshot of the BEST tool displaying the subsection "Building characteristics_Envelope description" inside the section "Architectural characteristics" with the case study data used for the analysis.

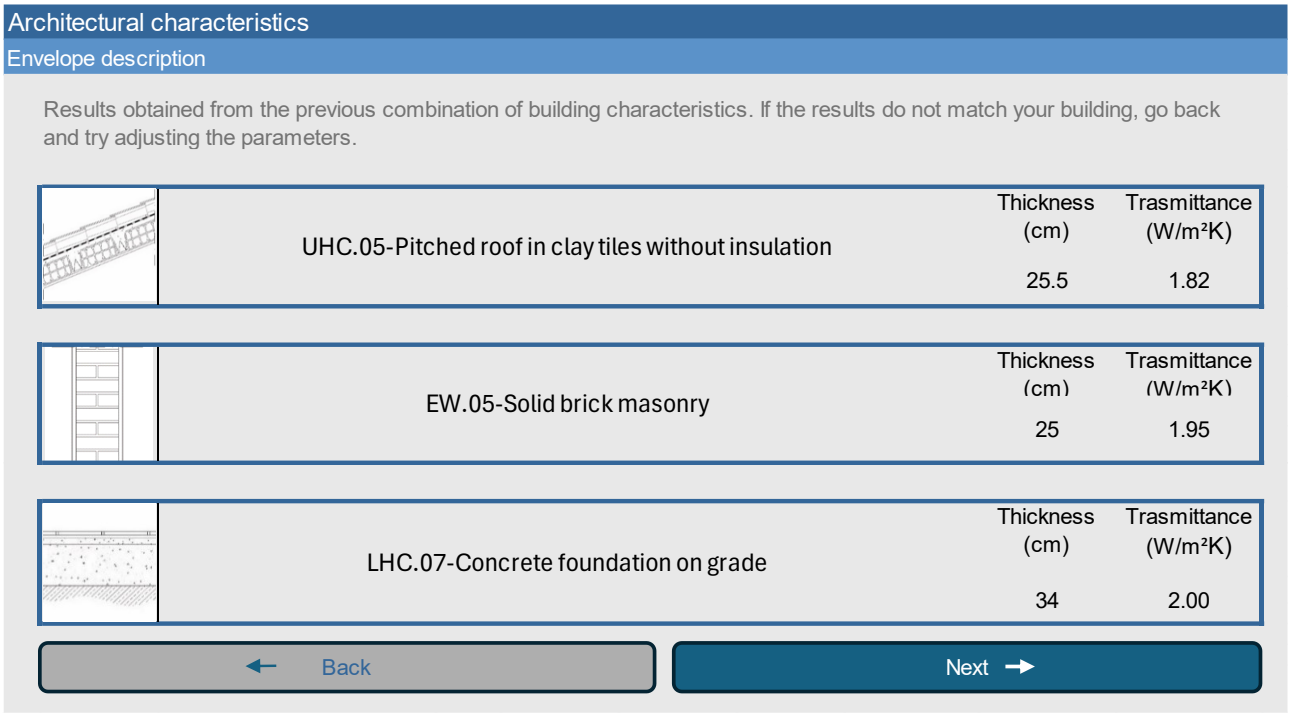



**Figure 7.** Screenshot of the BEST tool displaying the subsection "Building characteristics_Envelope description" inside the section "Architectural characteristics" with results obtained from the previous combination of building characteristics for the case study in analysis.

## 3. Interventions

*3.1. Applicable thermal insulation solutions*

Based on the envelope components selected by the user, the BEST tool suggests potential energy efficiency solutions applicable to Upper Horizontal Closures (UHC) and Vertical External Walls (EW).

The user may select the preferred solution according to the thickness of the insulating material, the thermal transmittance (U-value) of the building element, and the cost (€/m²).

The proposed solutions are categorized either by the type of thermal insulation intervention or by the position of the insulating layer relative to the building component. For Upper Horizontal Closures (UHC), the available options include:

- External Insulation (EI);
- External Ventilated Insulation (EVI);
- Internal Insulation (II).

For Vertical External Walls (EW), the options include:

- External Insulation System (EIS);
- Ventilated Wall (VW);
- Internal Insulation System (II).

The user will also be able to download a datasheet containing the results of the energy simulation, thus enabling a more informed selection of the optimal solution (**Supplement 2**).

Once the preferred solutions have been identified, the user will proceed with the configuration of the building's mechanical and energy systems.

Interventions

Applicable thermal insulation solutions

**Roof**

### External Insulation

| | | Insulation thickness (cm) | Trasmittance (W/m²K) | Cost (€/m²) | Technical Data Sheet |
|---|---|---|---|---|---|
| **UHC.05_ EI.01.b** | Thermal insulation system made of expanded polyisocyanurate (PIR) foam with a bitumen-coated felt facing | 10 | 0.2007 | 155.00 | PDF |
| **UHC.05_ EI.02.c** | Thermal insulation system in rigid polyurethane foam pre-bonded to a metallic water and air barrier layer | 10 | 0.2049 | 115.45 | PDF |
| **UHC.05_ EI.03.c** | Wood fiber thermal insulation system pre-bonded to a cement-bonded particleboard panel. | 16 | 0.2039 | 187.28 | PDF |

### External Ventilated Insulation

| | | Insulation thickness (cm) | Trasmittance (W/m²K) | Cost (€/m²) | Technical Data Sheet |
|---|---|---|---|---|---|
| **UHC.05_ EVI.01.b** | Insulation system composed of an EPS panel with ventilation channels, pre-bonded to a rock wool panel and an OSB board | 16 | 0.2039 | 187.28 | PDF |
| **UHC.05_ EVI.03.b** | Insulation system composed of a Neopor panel with ventilation channels, pre-bonded to an OSB board | 12 | 0.2079 | 170.50 | PDF |
| **UHC.05_ EVI.04.b** | Wood fiber insulating system bonded to an OSB panel, with interspersed wood layers creating an adequate ventilation gap | 16 | 0.2178 | 203.60 | PDF |

### Internal Insulation

| | | Insulation thickness (cm) | Trasmittance (W/m²K) | Cost (€/m²) | Technical Data Sheet |
|---|---|---|---|---|---|
| **UHC.05_ II.02.c** | Internal insulation system in aerogel pre-bonded to a plasterboard sheet | 6 | 0.2172 | 797.66 | PDF |
| **UHC.05_ II.03.b** | Internal insulation system in closed-cell rigid polyisocyanurate (polyiso) foam pre-bonded to a plasterboard sheet | 10 | 0.2013 | 85.64 | PDF |

← Back  Next →

**Figure 8.** Screenshot of the BEST tool displaying the subsection "Applicable thermal insulation solutions" inside the section "Interventions" with the types of thermal insulation interventions for the roof applicable to the case study.

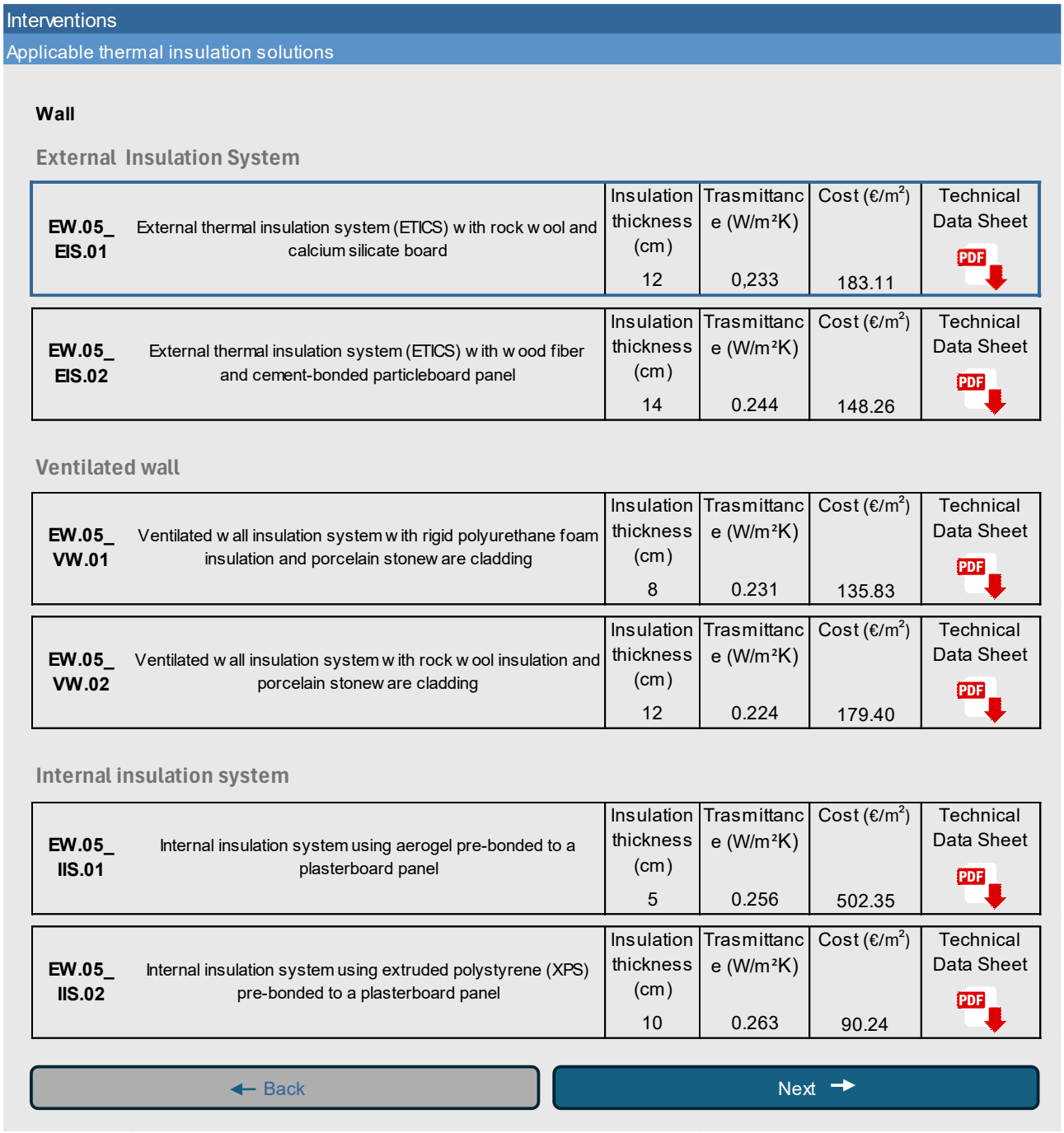



**Figure 9.** Screenshot of the BEST tool displaying the subsection "Applicable thermal insulation solutions" inside the section "Interventions"with the types of thermal insulation interventions for the wall applicable to the case study.

## 4. Systems and usage

*4.1. Building use*

Similar to the section concerning the "Architectural characterization" of the building, the definition of the mechanical system is also essential for calculating energy demands.

The first subsection, titled "Building Use", requires the specification of the operational schedule of the facility, which coincides with the maximum activation and deactivation times of the thermal systems.

Specifically, the following data must be provided:

- **Thermal system start-up time**: This refers to the time at which the heating and cooling systems can be switched on during the days when the facility is operational. The actual activation depends on the

internal ambient temperatures and the real heating/cooling needs. For office buildings, this generally corresponds to the opening time. If multiple activation periods occur within the same day, a single period should be entered, with a total duration equal to the sum of all periods.

- **Thermal system shutdown time**: This indicates the time at which the heating and cooling systems are turned off during the days when the facility is operational. For office buildings, this typically corresponds to the closing time. If multiple activation periods occur within the same day, a single period should be entered, with a total duration equal to the sum of all periods.
- **Total duration of thermal system activation period (hours per day)**: This represents the maximum number of daily hours during which the heating/cooling systems can be operational on days when the facility is in use. The actual activation duration depends on the facility's real thermal requirements. For office buildings, this generally corresponds to the daily opening hours.

Additionally, within the first subsection, it is necessary to specify the days on which the facility is occupied and active:

- **Building operating days**: This information is crucial for determining the days when the building is effectively occupied. On days when it is not in use, the building remains vacant, and the systems remain off. The active days are appropriately distributed throughout the year according to one of the following options:
  - **According to the building's intended use:** The number of operational days is estimated based on typical usage, with an average of 180 days per year for continuously occupied residences, 50 days per year for occasional residences, 113 days per year for office buildings, and 82 days per year for schools.
  - **Every day:** The facility operates 365 days per year.
  - **Every day except public holidays:** All national holidays are excluded, resulting in 354 operational days per year.
  - **Every day except public holidays and summer vacation:** All national holidays and a portion of summer vacation days are excluded, resulting in 345 operational days per year.
  - **Six days per week, excluding vacation:** The facility operates six days per week, with all national holidays and a portion of summer vacation days excluded, resulting in 300 operational days per year.
  - **Five days per week, excluding public holidays:** The facility operates five days per week, excluding all national holidays, resulting in 252 operational days per year.
- **Number of operational days**: This represents the total number of days during which the building is effectively occupied. On unoccupied days, the building remains vacant, and the systems remain off. On occupied days, the systems may be activated based on actual heating and cooling demands. The active days are distributed appropriately throughout the year.

Finally, the first subsection requires the specification of the number of occupants present in the building when it is in use:

- **Average number of occupants**: This indicates the number of people who are typically present in the building during operational days. The number of occupants influences the magnitude of internal loads. The minimum number of people suggested by UNI 10339 for ventilation flow rate calculations is also provided, corresponding to three individuals.

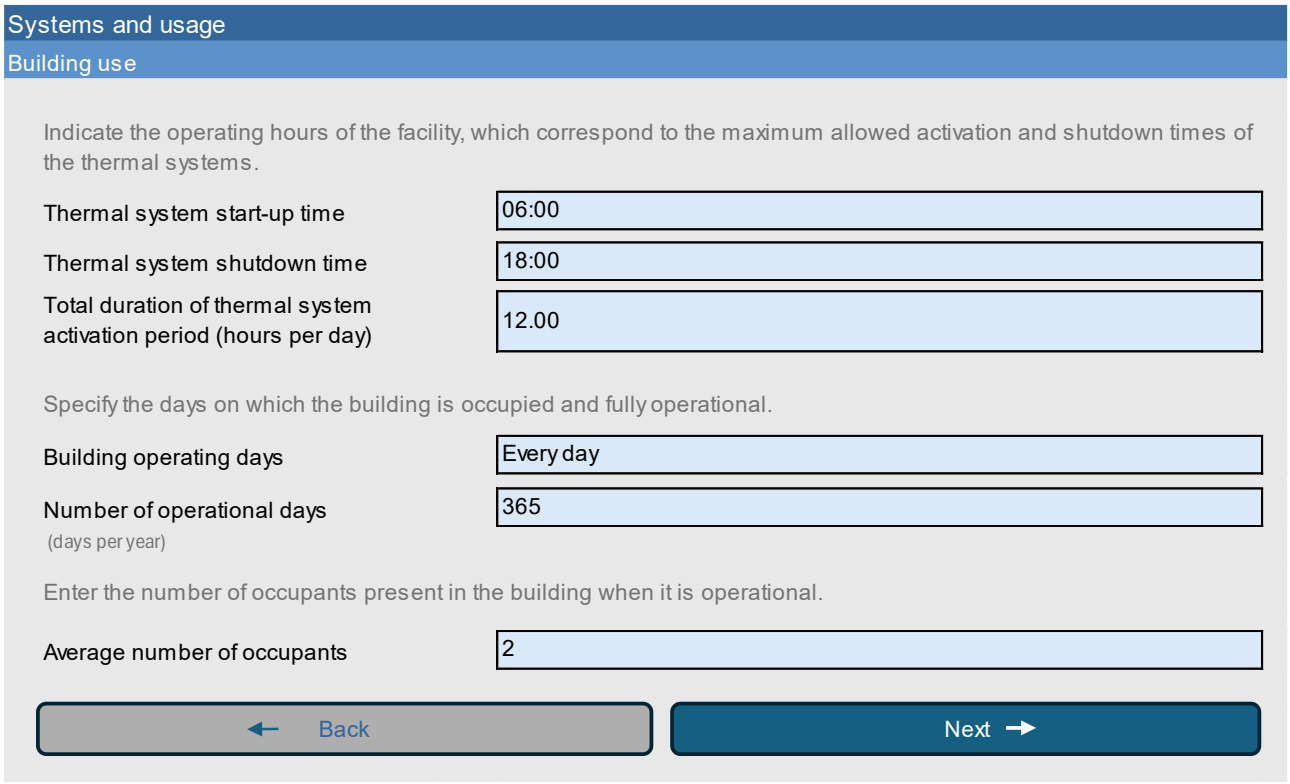



**Figure 10.** Screenshot of the BEST tool displaying the subsection "Building use" inside the section "System and usage" with the case study data used for the analysis.

*4.2. Heating system*

The second subsection of the "Systems and Usage" section pertains to "Heating Systems" and includes the following data:

- **Presence of the heating system**: Indicate "YES" if a heating system is present.
- **Period of piping installation**: This refers to the installation period of the air/water distribution network of the heating system. The heat generator itself may be more recent. This information is essential for determining the level of insulation of the distribution network and, consequently, its efficiency.
- **Heat generator installation period**: This indicates the installation period of the heat generator of the heating system. The data influences the technology used in the heat generator and its corresponding generation efficiency.
- **Heated area percentage**: Represents the percentage of the building served by the heating system. This percentage can range from 1% to 100% and allows for a linear reduction in the thermal demand of the zone due to the unheated portion. It is recommended to indicate this value as the percentage ratio between the heated volume and the total volume.
- **Winter temperature control setpoint**: Refers to the heating system's setpoint temperature. This parameter is non-modifiable as it is regulated by DPR 412/93. Upon activation, the heating system will attempt to reach the setpoint temperature within approximately two hours and maintain it consistently. If the generator's power is insufficient to sustain the designated setpoint temperature, an error will be displayed next to the "Dedicated Generator Thermal Power" field.
- **Predominant type of heat generator**: Specify whether the generator is a traditional boiler, a condensing boiler, or a heat pump.
- **Generator thermal power**: Represents the useful thermal power delivered by the generator to meet the heating demand of the simulated zone. The actual power delivered to the environment is lower due to losses in the distribution, emission, and regulation subsystems. If the input power is insufficient to maintain the designated setpoint temperature, an error message will be displayed, and the power must be increased. Significant discrepancies between the indicated and actual generator power may suggest

an error in model configuration. Data should be verified. If the input value is too low, it will be discarded, and an internally calculated value will be used. If the generator also serves other buildings or apartments not included in the present simulation, only a portion of the total generator power should be specified. The division may be proportional to the simulated zone volume relative to the total volume (P_zone = V_zone/V_tot * P_tot).

- **Seasonal thermal efficiency of the generator**: Seasonal thermal efficiency (for boilers) or seasonal coefficient of performance (SCOP) (for heat pumps), calculated in accordance with UNI TS 11300 standards as P_useful/P_absorbed.
- **System type**: Indicate only internal units with natural ventilation.
- **Type of internal units**: If the heating system includes internal units, specify the predominant type. Possible options include:
  - **Radiators (convectors):** Traditional natural convection radiators supplied with high-temperature water (T=55-70°C). Suitable only for heating and only with generators capable of producing high-temperature water.
  - **Fan coils or split units:** Forced convection units equipped with fans. Two possible supply types: either medium-temperature water (T=35-55°C) or direct expansion refrigerant gas. The first option is suitable for boilers or hydronic heat pumps; the second is suitable only for direct expansion heat pumps.
  - **Radiant panels:** Radiant systems embedded in floors, ceilings, or walls, supplied with low-temperature water (T=25-35°C). Suitable for condensing boilers or hydronic heat pumps.
- **Air handling unit (AHU) flow rate**: Indicates the airflow regulation mode for mechanical ventilation. The flow rate is calculated following UNI TS 11300 standards based on three regulation modes, ranked by increasing efficiency:
  - **Fixed (design value):** The airflow remains constant during unit operation.
  - **Variable based on occupancy (presence sensors):** The airflow varies according to the presence of occupants. This requires occupancy sensors in rooms, variable-speed fans (inverter-driven), and potential zone dampers.
  - **Variable based on air quality (CO2 sensors):** The airflow varies according to the indoor CO2 concentration. This requires CO2 sensors in rooms or ducts, variable-speed fans (inverter-driven), and potential zone dampers.
- **Presence of heat recovery unit**: Indicates the presence of a crossflow heat recovery unit between the intake and exhaust of renewal air. This is only possible with controlled mechanical ventilation. The heat recovery efficiency is set at 50%.
- **Heating regulation mode**: Describes the system for controlling and regulating indoor temperature:
  - **Weather-compensated boiler control:** A single temperature sensor in the boiler room, without thermostats in the rooms.
  - **Manual thermostat:** A single manually operated thermostat for the entire building.
  - **Programmable thermostat:** A single thermostat for the entire building, programmable for all hours of the week.
  - **Thermostat and thermostatic valves:** A central thermostat and manually adjustable thermostatic valves on each radiator to set room-specific temperatures.
  - **Programmable thermostat and thermostatic valves:** A central thermostat and programmable thermostatic valves on each radiator to set weekly room-specific temperatures.
  - **Programmable thermostat in each room:** A weekly programmable thermostat in each room to set desired temperatures.
  - **Remote control for each unit:** Each internal unit is equipped with a remote control for temperature regulation using PID control. This is typical for modulating direct expansion heat pumps (inverter-type split units).

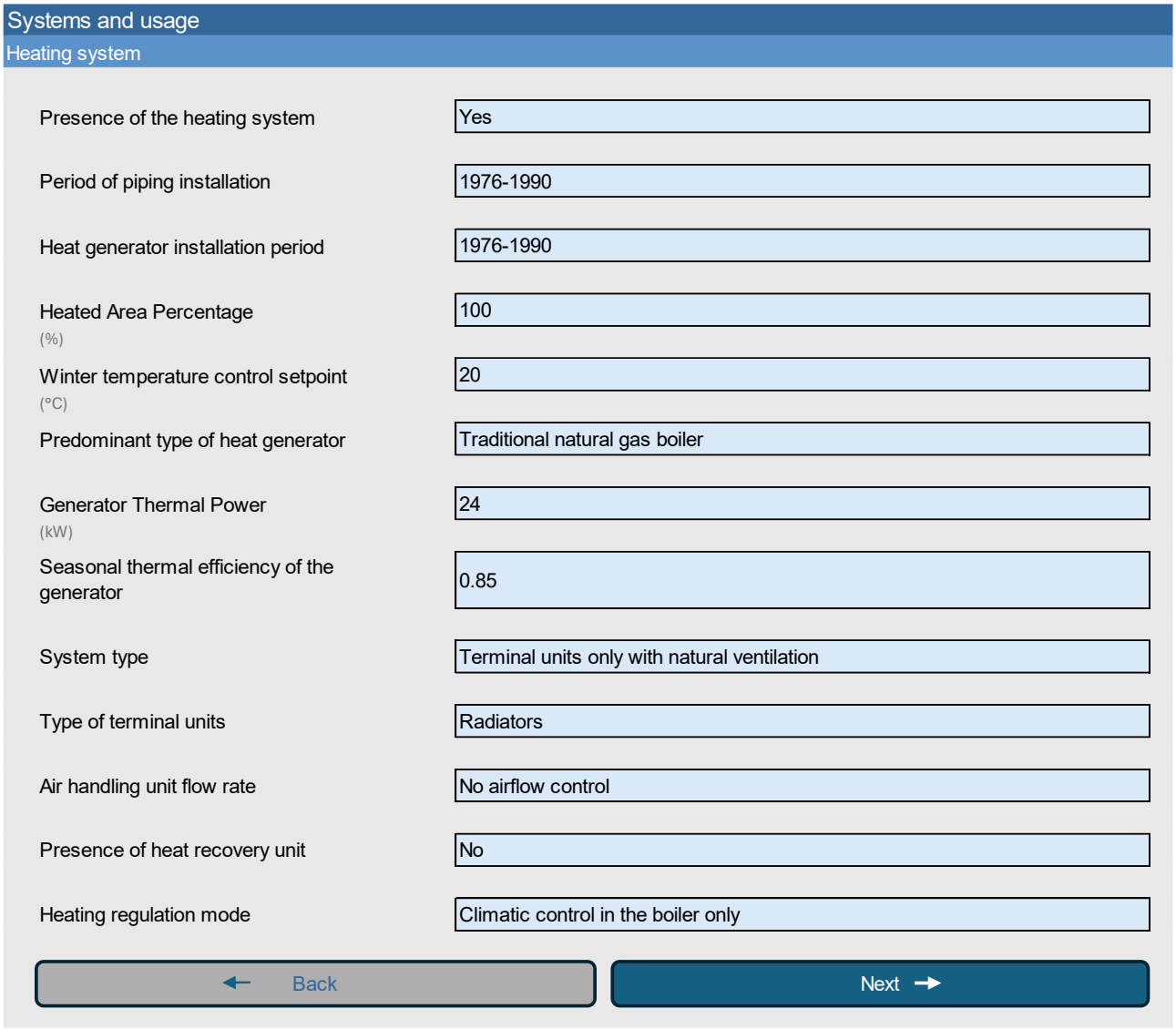



**Figure 11.** Screenshot of the BEST tool displaying the subsection "Heating system" inside the section "System and usage" with the case study data used for the analysis.

### *4.3. Cooling System*

The third subsection defines the "Cooling System" and includes the following information:

- **Presence of the cooling system**: Indicate "YES" if a cooling system is present.
- **Period of piping installation**: Refers to the installation period of the air/water distribution network of the cooling system. The cooling generator may be more recent. This data is essential for assessing the insulation level of the distribution network and its efficiency.
- **Chiller installation period**: Refers to the installation period of the cooling system's generator. This data affects the generator's technology and its generation efficiency.
- **Percentage of cooled spaces**: Represents the percentage of the building served by the cooling system. This percentage ranges from 1% to 100% and allows for a linear reduction in thermal demand for the zone, considering that part of it is not cooled. It is recommended to express this data as the percentage ratio between the cooled volume and the total volume.
- **Summer setpoint temperature**: Denotes the set-point temperature of the cooling system. This value is non-modifiable as per DPR 412/93. Upon activation, the cooling system will attempt to bring the internal building temperature to the set-point value within approximately two hours and maintain it consistently. If the generator's power is insufficient to sustain the specified set-point temperature, an error message will be displayed next to the field "Dedicated generator thermal power."

- **Predominant cooling unit type**: Indicate the technology of the primary cooling generator. If multiple generators are present, specify the one with the highest capacity. The possible choices are:
  - **Air-to-water (hydronic) heat pump or electric chiller**: An electrically powered heat pump (or chiller) using vapor compression, air-evaporated, and connected to a water-based thermal network. EER depends on the installation year.
  - **Air-to-air (direct expansion) heat pump or electric chiller**: An electrically powered heat pump (or chiller) using vapor compression, air-evaporated, and connected to terminals using refrigerant gas. EER depends on the installation year.
  - **District cooling**: A cooling system supplied by an external refrigerant network.
- **Cooling unit thermal power**: Represents the useful cooling power supplied by the generator to meet the simulated zone's needs. The actual cooling power delivered to the spaces is lower due to distribution, emission, and regulation losses. If the power is insufficient to maintain the specified set-point temperature, an error message will appear, requiring an increase in power. If the entered value significantly deviates from the generator's actual power, it may indicate a modeling error—please verify the data. If the value is too low, it will be discarded and replaced with an internally calculated value. If the generator also serves other buildings or apartments outside the current simulation, only a portion of its total power should be entered. This distribution can be proportional to the volume of the simulated zone relative to the total volume (P_zone = V_zone/V_tot * P_tot).
- **Seasonal energy efficiency ratio (SEER):** Indicates the seasonal efficiency (SEER) of the cooling generator, calculated according to UNI TS 11300 standards as: P_useful/P_absorbed.
- **System type**: Specify only internal units with natural ventilation.
- **Type of terminal units**: In the case of an air-conditioning system with internal units, specify the predominant unit type. The possible options are:
  - **Fan coil (convectors) or split units:** Forced convection units with fans. Two possible power sources: water at low temperature (T = 5-12°C) or direct expansion with refrigerant gas. The first option is suitable for hydronic heat pumps, while the second is only suitable for direct expansion heat pumps.
  - **Radiant panels:** Radiant systems embedded in floors, ceilings, or walls, powered by water at medium temperature (T = 12-18°C). Suitable for hydronic heat pumps.
  - **Air handling unit airflow rate:** Refers to the regulation mode of the airflow rate for mechanical ventilation. The airflow rate is determined according to UNI TS 11300 standards, based on three efficiency-increasing regulation modes:
  - **Fixed (design value):** The airflow rate remains constant during unit operation.
  - **Variable based on occupancy (presence sensors):** The airflow rate varies in response to occupancy levels. Requires presence sensors in rooms, variable-speed fans (inverter-driven), and optional zone dampers.
  - **Variable based on air quality (CO2 sensors):** The airflow rate varies according to indoor CO2 concentration. Requires CO2 sensors in rooms or ducts, variable-speed fans (inverter-driven), and optional zone dampers.
- **Airflow rate of the air handling unit:** The airflow rate is calculated in accordance with the UNI TS 11300 standard, based on three possible regulation modes with increasing efficiency:
  - **Fixed (design) flow rate:** The airflow rate remains constant throughout the operation of the unit.
  - **Variable flow rate based on occupancy (occupancy sensors):** The airflow rate varies in response to the presence of occupants. This mode requires occupancy sensors in the rooms, variable speed fans (inverter-driven), and, where applicable, zonal dampers.
  - **Variable flow rate based on air quality ($CO_2$ sensors):** The airflow rate adjusts according to the concentration of $CO_2$ in the indoor air. This system requires $CO_2$ sensors in the rooms or ducts, variable speed fans (inverter-driven), and, where applicable, zonal dampers.
- **Presence of a heat recovery unit**: Indicates the presence of a crossflow heat exchanger between the supply and exhaust air streams. Available only in systems with controlled mechanical ventilation. The heat exchanger efficiency is fixed at 50%.
- **Cooling regulation mode**: Describes the control and regulation system for indoor temperature:

- **Manual thermostat: A** single manually operated thermostat for the entire building.
- **Programmable thermostat:** A single thermostat for the entire building, programmable for all hours of the week.
- **Programmable thermostat in each room:** A weekly programmable thermostat in each room to maintain the desired temperature.
- **Remote control for each unit:** Each internal unit is equipped with a remote control for temperature regulation using PID control. This is a typical solution for direct expansion modulating heat pumps (inverter-driven split units).

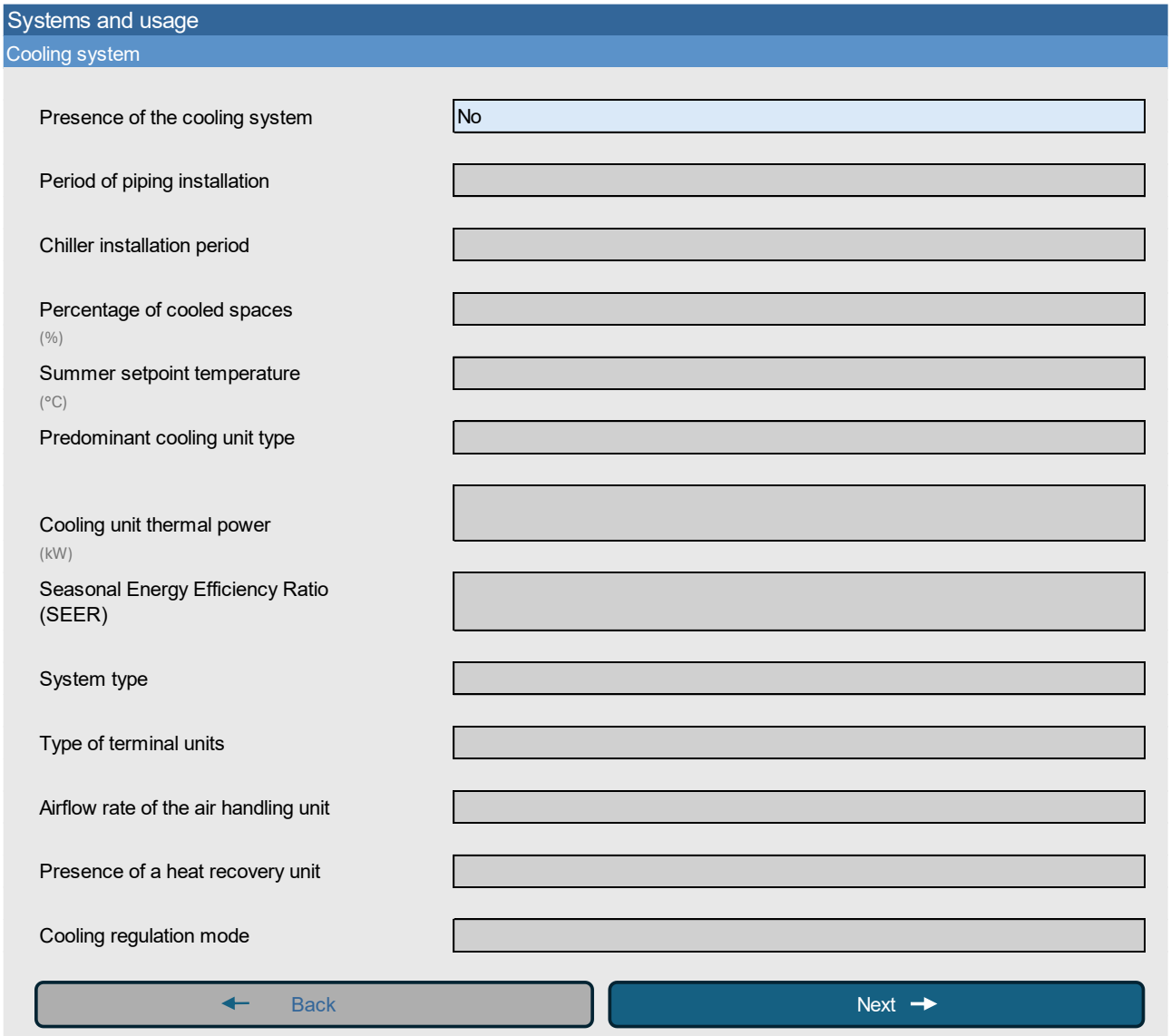



**Figure 12.** Screenshot of the BEST tool displaying the subsection "Cooling system" inside the section "System and usage" with the case study data used for the analysis.

*4.4. Domestic hot water (DHW) system*

In the fourth subsection titled "Domestic Hot Water Preparation System," the following data are defined:

- **Domestic hot water (DHW) system:** This refers to the method used to prepare hot water for sanitary uses (DHW), such as for showers and kitchens. The options available are:
  - **None:** No DHW preparation.
  - **Same Generator as heating system:** DHW is prepared using the same generator used for heating the indoor spaces. An error will appear if the generator is not compatible with DHW preparation. It

is assumed that heat pumps used for cooling are not capable of preparing DHW, and a specific heat pump should be entered.
    - **Instantaneous natural gas boiler:** A traditional or condensing natural gas boiler that produces hot water instantly when needed (without storage).
    - **Condensing natural gas boiler with integrated storage:** A natural gas condensing boiler that prepares DHW and stores it in a tank (boiler) for immediate use.
    - **Heat Pump with integrated storage:** A heat pump specifically for DHW that heats water and stores it in a tank (boiler) for later use.
    - **Electric Water Heater:** A traditional water heater that heats water using an electric resistance and stores it in a tank (boiler) for later use.
- **Presence of a storage system (boiler):** This defines whether there is a thermally insulated storage tank for storing DHW. For some generators, the choice is not free, and an error will appear if the selection is incorrect. The options are:
    - **None:** No storage, DHW is produced and used instantly as needed.
    - **Yes, within the heated zones:** There is at least one storage tank located inside the building in a heated zone.
    - **Yes, outside the heated zones:** There is at least one storage tank located outside the building or in a non-heated zone.

  If there are multiple tanks with different characteristics, the most common value should be entered.
- **Number of storage tanks (boilers):** Indicates the number of DHW storage tanks present in the building.
- **Average capacity of each storage tank:** Defines the average capacity in liters of the storage tanks. If multiple tanks with different characteristics are present, an average value should be entered. Typical electric water heaters have sizes ranging from 20 liters (very small) to 80 liters (tall cylinders approximately 70-80 cm high).

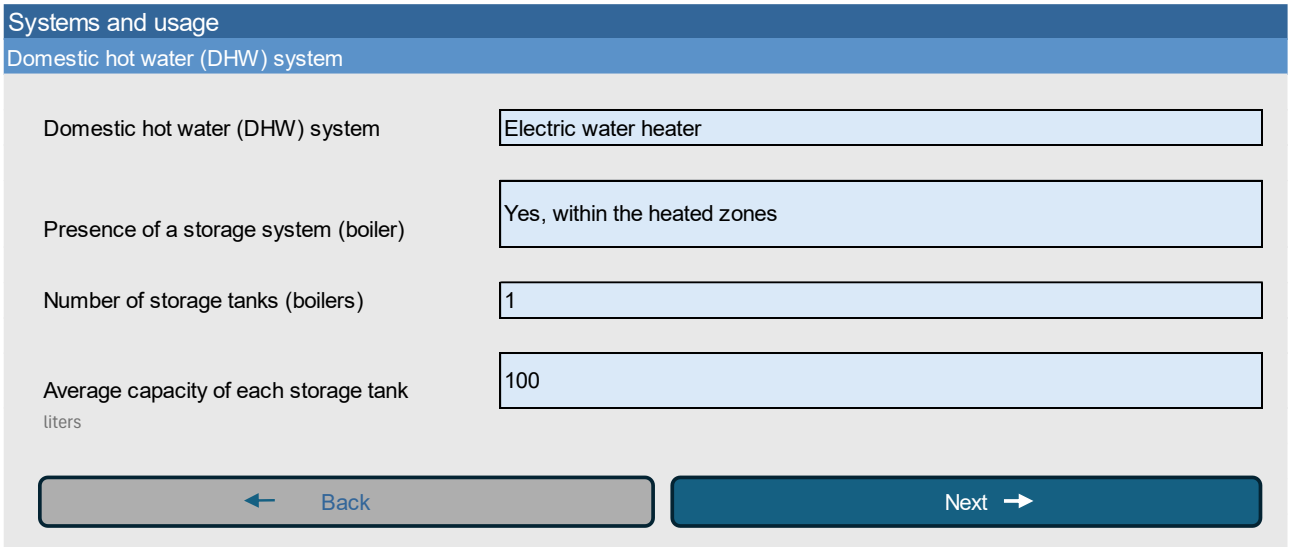



**Figure 13.** Screenshot of the BEST tool displaying the subsection "Domestic hot water (DHW) system" inside the section "System and usage" with the case study data used for the analysis.

*4.5. Solar thermal system (for hot water)*

The fifth subsection defines the specifications for the "Solar Thermal System (for Domestic Hot Water)" and contains the following information:

- **System type:** Refers to the type of solar thermal system used for preparing domestic hot water. Heating of spaces through solar thermal energy is not considered. The available options are:
    - **None:** No solar thermal system.

    - **Flat plate collectors with natural circulation:** A typical solar thermal panel with a glazed flat absorber, where water circulation is natural, meaning it does not require pumps. These panels can be identified because they are always equipped with a storage tank located above the panel itself.
    - **Flat plate collectors with forced circulation:** A typical solar thermal panel with a glazed flat absorber, where water circulation is forced, meaning it requires pumps. These panels can be identified because they do not have a storage tank located above the panel.
    - **Vacuum tube collectors with natural circulation:** A solar thermal panel with an absorber made of metal sheets inside vacuum glass tubes. These panels are more efficient and suited for lower temperatures. The circulation of water is natural (without pumps). These panels can be identified by their long transparent cylinders and are always equipped with a storage tank located above the panel.
    - **Vacuum tube collectors with forced circulation:** A solar thermal panel with an absorber made of metal sheets inside vacuum glass tubes. These panels are more efficient and suited for lower temperatures. The circulation of water is forced, requiring pumps. These panels can be identified by their long transparent cylinders and do not have a storage tank located above the panel.
- **Number of solar thermal panels:** Indicates the number of solar thermal panels used for domestic hot water production. The panels are assumed to be of standard size, 2m² each.
- **Tilt angle:** Defines the tilt angle of the panels in relation to the horizontal plane. The available values are:
    - **0°:** Horizontal.
    - **15°-20°:** Typical roof inclination angle.
    - **30°:** Angle required to maximize annual production for a southern orientation.
    - **45°:** Optimal angle for winter energy production, i.e., during periods of peak domestic hot water demand.
    - **90°:** Vertical.
- **Azimuth relative to the south** Represents the orientation of the panels relative to geographical south. The available values are:
    - **-90°:** East.
    - **-45°:** South-East.
    - **0°:** South (optimal).
    - **45°:** South-West.
    - **90°:** West.

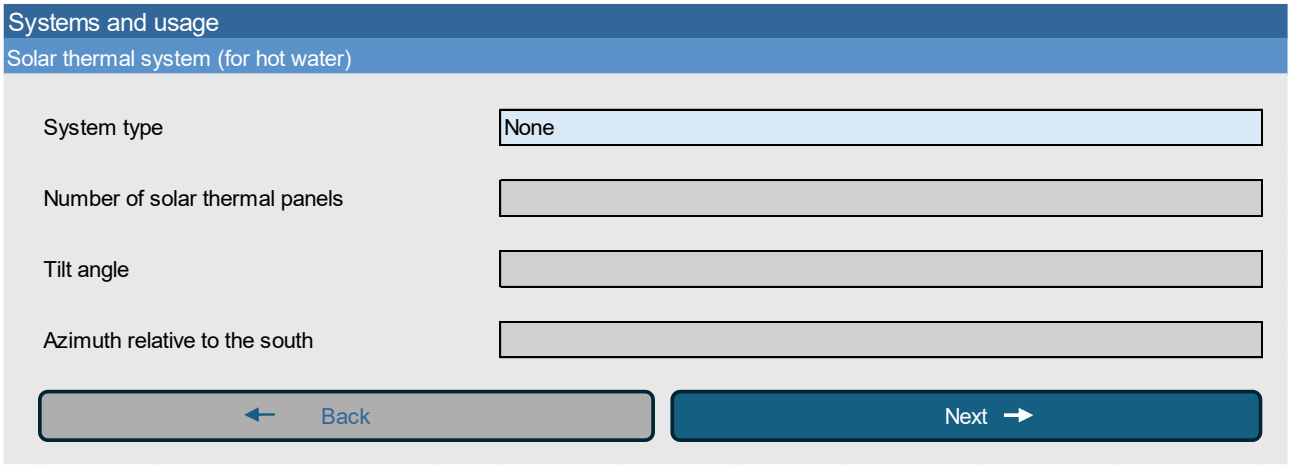



**Figure 14.** Screenshot of the BEST tool displaying the subsection "Solar thermal system (for hot water)" inside the section "System and usage" with the case study data used for the analysis.

*4.6. Photovoltaic solar system (for electricity)*

The sixth and final subsection related to systems and their use defines the "Photovoltaic Solar System (for electricity)" and is broken down into the following points:

- **System type:** Refers to the type of photovoltaic system for generating electricity from the sun. The available options are:
  - **None:** No photovoltaic system.
  - **Monocrystalline or polycrystalline photovoltaic panels:** A typical rigid flat photovoltaic module with monocrystalline or polycrystalline silicon cells.
- **Available space for a potential photovoltaic (PV) system:** Refers to the surface area available that could be used for installing a photovoltaic system, in case there isn't already one. This space will be used to evaluate the potential improvement from installing a photovoltaic system.
- **Photovoltaic system power:** Indicates the peak power of the photovoltaic system, calculated as the sum of the peak powers of the individual modules.
- **Tilt angle:** If a system is present, it indicates the tilt angle of the panels in relation to the horizontal plane. If no system is present but only a potentially usable surface, the tilt of the surface on the horizontal plane should be indicated. This will be used to evaluate the effect of installing a system. In the case of a flat roof (tilt <5°), the panels will be positioned with the optimal orientation and tilt. In the case of a sloped roof, the panels will be positioned parallel to it. The options are:
  - **0°:** Horizontal.
  - **15°-20°:** Typical roof tilt angle.
  - **30°:** Optimal angle for photovoltaic panels facing South.
  - **90°:** Vertical.
- **Azimuth relative to the south:** If a system is present, it indicates the orientation of the panels relative to geographical south. If no system is present but only a potentially usable surface, the orientation of the surface relative to geographical south should be indicated. This will be used to evaluate the effect of installing a system. In the case of a flat roof (tilt <5°), the panels will be positioned with the optimal orientation and tilt. In the case of a sloped roof, the panels will be positioned parallel to it. The orientation of the panels relative to geographical south can be:
  - **-90°:** East.
  - **-45°:** South-East.
  - **0°:** South (optimal).
  - **45°:** South-West.
  - **90°:** West.

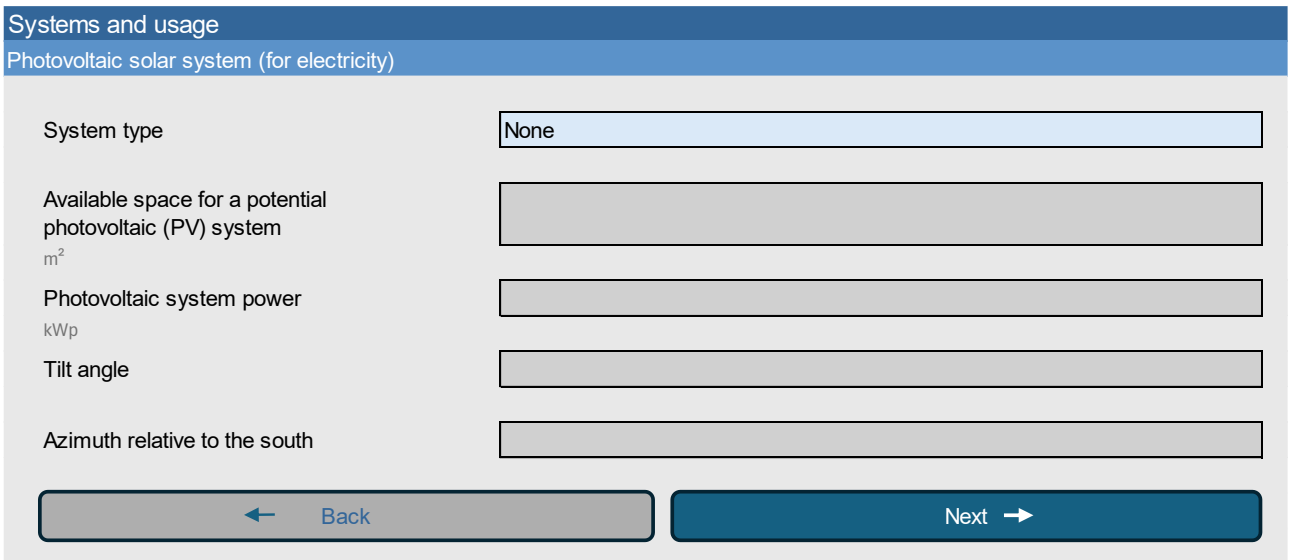



**Figure 14.** Screenshot of the BEST tool displaying the subsection "Photovoltaic solar system (for electricity)" inside the section "System and usage" with the case study data used for the analysis.

## 5. Economic and energy indicators

This section of the BEST tool provides a configurable set of economic and energy parameters that influence the calculation of energy efficiency performance and cost-effectiveness of retrofit interventions. By default, these parameters are pre-filled with standardized values based on typical market conditions. However, the user retains the ability to modify them in order to reflect project-specific assumptions or updated economic data. The parameters include:

- **General inflation (%)**: Represents the projected annual increase in overall prices, impacting long-term economic evaluations.
- **Energy inflation (%)**: Reflects the expected annual increase in energy prices, crucial for assessing future operational savings.
- **Implementation rate (%)**: Defines the discount rate or return on investment, used to calculate the net present value of energy savings.
- **Cost of electricity including VAT (€/kWh)**: Indicates the unit cost of electricity, inclusive of value-added tax, as paid by the end user.
- **Cost of natural gas including VAT (€/sm³)**: Indicates the unit cost of natural gas, inclusive of VAT.
- **VAT on electricity (%)**: Specifies the applicable VAT rate on electricity consumption.
- **VAT on gas (%)**: Specifies the applicable VAT rate on natural gas consumption.

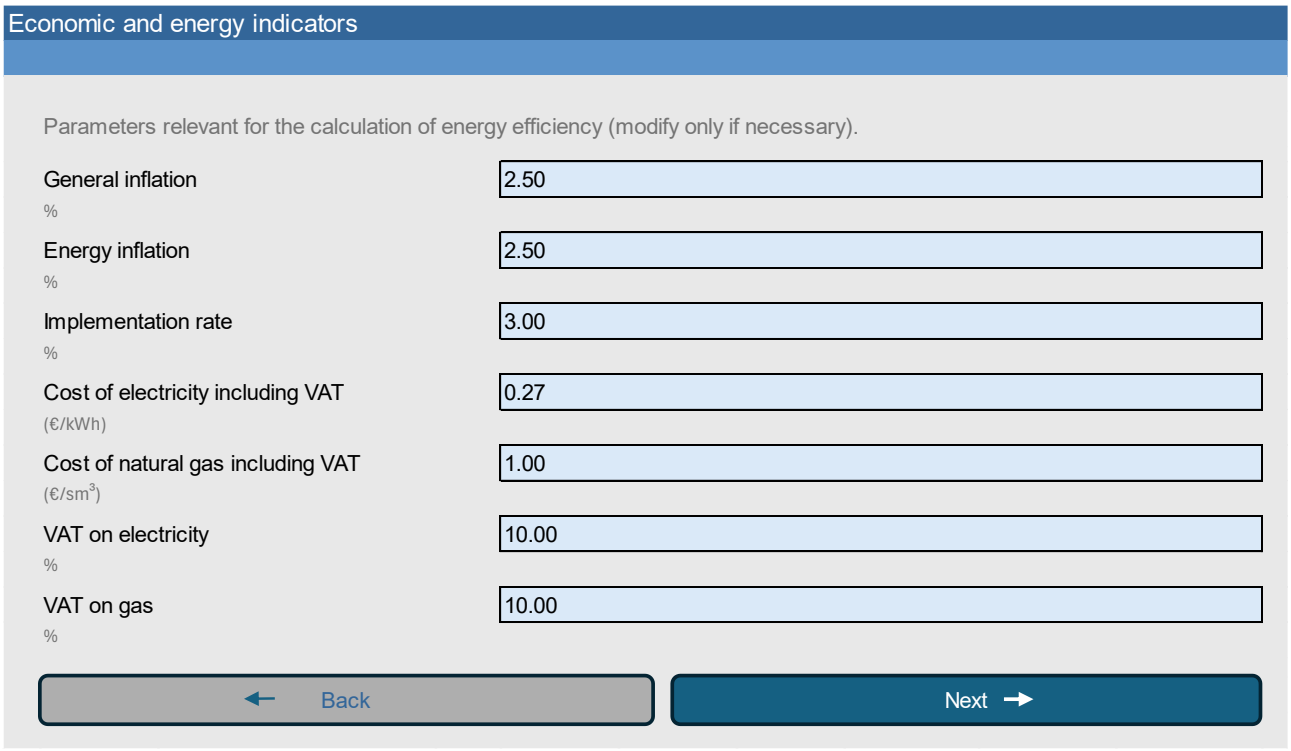



**Figure 14.** Screenshot of the BEST tool displaying the section "Economic and energy indicators".

## 6. Procedure for the control and management of errors in the compiled data

Once all the selection fields related to the sections "General Data," "Architectural Features," and "Systems and Use" have been completed, the application allows for a final check to identify any errors. If errors are found, a warning message (alert) will be displayed, indicating the nature of the error. The user will be prompted to choose one of the following actions:

- Recalculate the data by using the "Recalculate" button;
- Restore a previous configuration by pressing the CTRL+Z key combination to revert to a working state;
- Close and reopen the application to reset the situation.

If, despite these actions, the errors persist, a new complete data entry process will be necessary. It is recommended to carefully check the correctness of each section before re-executing the check.

## 7. Calculation start

Once the input data have been verified and no compilation errors are present, the simulation of the energy retrofit interventions can be initiated.
The calculation process is then launched, and the user must wait a few minutes for the results to be generated. The simulation is not instantaneous due to the complexity of the underlying analysis.
Upon completion, a summary table becomes available. This includes the "As-is condition", which describes the current state of the building, followed by three proposed energy efficiency improvement scenarios.

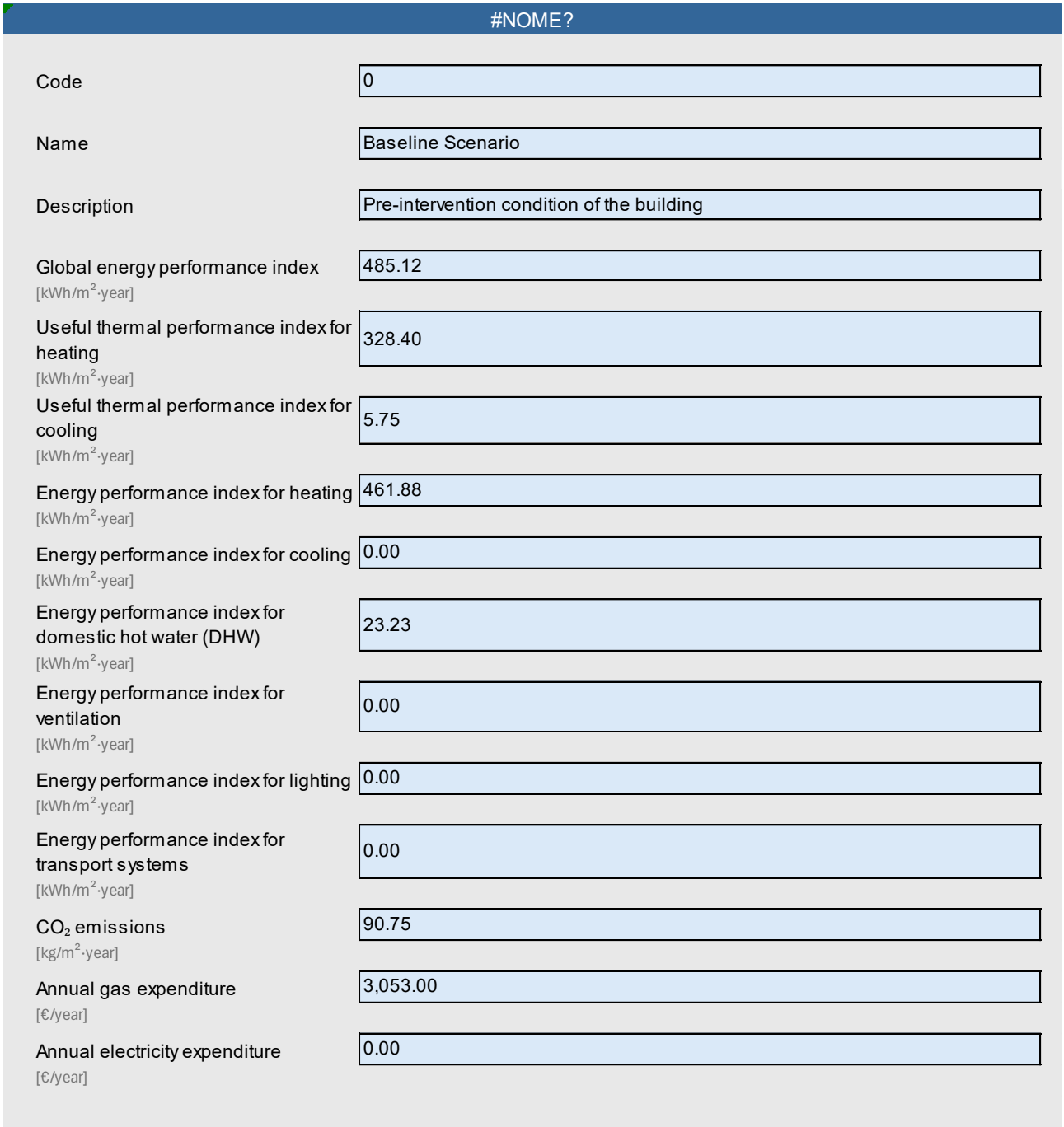



**Figure 15.** Screenshot of the BEST tool displaying the "As-is condition" of the case study.

## 8. Results

The output of the tool consists of a **comparative table** presenting three different energy retrofit strategies for the building's opaque envelope. Each intervention is described through a set of key indicators that allow for an in-depth comparison in terms of energy performance, environmental impact, and economic feasibility.

For each intervention, the following information is provided:

- **Code**: A unique identifier for the proposed intervention (*INT.n°*).
- **Name**: The title or designation of the energy efficiency measure.
- **Description**: A detailed explanation of the type of intervention applied to the building envelope (external insulation, ventilated wall systems, etc.).
- **Global energy performance index (kWh/m²·year)**: Represents the total annual energy demand per square meter, combining all end-uses, including heating, cooling, domestic hot water, ventilation, lighting, and transportation systems.
- **Useful thermal performance index for heating (kWh/m²·year)**: Indicates the amount of thermal energy required to maintain indoor comfort in winter conditions, without accounting for system inefficiencies.
- **Useful thermal performance index for cooling (kWh/m²·year)**: Measures the thermal energy needed to cool the building during summer periods, prior to conversion losses.
- **Energy performance index for heating (kWh/m²·year)**: Reflects the actual delivered energy required for heating, taking into account system efficiency and distribution losses.
- **Energy performance index for cooling (kWh/m²·year)**: Accounts for the delivered energy used for cooling the indoor environment.
- **Energy performance index for domestic hot water (DHW) (kWh/m²·year)**: Represents the energy consumption associated with domestic hot water production.
- **Energy performance index for ventilation (kWh/m²·year)**: Quantifies the energy consumed by mechanical ventilation systems, including fans and heat recovery units.
- **Energy performance index for lighting (kWh/m²·year)**: Captures the electricity demand of artificial lighting systems.
- **Energy performance index for transport systems (kWh/m²·year)**: Includes energy used for vertical and horizontal transportation (elevators and escalators) within the building.
- **$CO_2$ emissions [kg/m²·year]**: Total annual greenhouse gas emissions per square meter, resulting from energy consumption associated with each intervention scenario.
- **Annual gas expenditure [€/year]**: Estimated yearly cost for natural gas consumption, reflecting the selected energy tariffs and usage levels.
- **Annual electricity expenditure [€/year]**: Estimated yearly cost for electricity consumption, including taxes and fees.
- **Investment [€]**: The capital expenditure required to implement the proposed intervention.
- **Net Present Value (NPV, 20 years) [€]**: Represents the economic value generated over a 20-year period, net of the initial investment, and accounting for inflation. The NPV is calculated relative to the "as-is" scenario (i.e., without intervention).
  - If **NPV = 0**, the investment cost is fully recovered, with neither gains nor losses.
  - If **NPV > 0**, the intervention yields financial benefits beyond the recovery of the initial investment.
  - If **NPV < 0**, the intervention fails to recoup its upfront cost.
    The calculation may include or exclude tax incentives, depending on the user's selection in the previous section.
- **Payback Time (PBT) [years]**: Indicates the number of years required for the cumulative savings to offset the initial investment, considering inflation. Beyond the PBT, the building will generate net savings for the remainder of its service life. This metric is also calculated in relation to the baseline (no-intervention) scenario, with or without incentives.

- **$CO_2$ Emissions reduction [kg/m²·year]**: Denotes the quantity of $CO_2$ emissions avoided annually compared to the baseline scenario, as a result of implementing the intervention.
- **Consumption reduction [%]**: Represents the percentage decrease in overall energy consumption relative to the current (as-is) condition of the building.

| Evaluated interventions | | | |
|---|---|---|---|
| Code | INT.01 | INT.02 | INT.03 |
| Name | Roof Thermal Insulation | Wall Thermal Insulation | Combined Wall and Roof Thermal Insulation |
| Description | External roof insulation with rigid polyurethane foam panels (IE.01.b) | External thermal insulation system with glass wool panels (EI.01) | Combination of wall insulation with glass wool panels (EI.01) and roof insulation with rigid polyurethane foam panels (IE.01.b) |
| Global energy performance index [kWh/m²·year] | 371.87 | 295.09 | 185.53 |
| Useful thermal performance index for heating [kWh/m²·year] | 244.57 | 185.60 | 103.34 |
| Useful thermal performance index for cooling [kWh/m²·year] | 7.44 | 11.71 | 17.11 |
| Energy performance index for heating [kWh/m²·year] | 348.64 | 271.64 | 162.08 |
| Energy performance index for cooling [kWh/m²·year] | 0.00 | 0.00 | 0.00 |
| Energy performance index for domestic hot water (DHW) [kWh/m²·year] | 23.23 | 23.45 | 23.45 |
| Energy performance index for ventilation [kWh/m²·year] | 0.00 | 0.00 | 0.00 |
| Energy performance index for lighting [kWh/m²·year] | 0.00 | 0.00 | 0.00 |
| Energy performance index for transport systems [kWh/m²·year] | 0.00 | 0.00 | 0.00 |
| $CO_2$ emissions [kg/m²·year] | 69.57 | 55.20 | 34.71 |
| Annual gas expenditure [€/year] | 2,340.00 | 1,860.00 | 1,170.00 |
| Annual electricity expenditure [€/year] | 0.00 | 0.00 | 0.00 |
| Investment [€] | 14,148.40 | 16,395.32 | 30,543.72 |
| NPV (20 years) [€] | 3,546.00 | 1,343.54 | -2,525.73 |
| PTB [years] | 19 years and 10 months | 13 years and 9 months | > 20 years |
| $CO_2$ emissions reduction [kg/m²·year] | 21.18 | 35.55 | 56.04 |
| Consumption reduction [%] | 23.35 | 39.17 | 61.76 |

**Figure 16.** Screenshot of the BEST tool displaying the "Evaluated interventions" for the case study.