HeriTACE

Baseline Scenarios

Deliverable D5.4

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Executive Summary

A key objective of the HeriTACE project is the development of a holistic and multi-scale integrated approach for the deep renovation of heritage townhouses, that allows to reduce the overall building energy demand by 60% and prepares the building for a fossil-free energy supply. This task (T5.2) defines the holistic set of performance indicators that are assessed within this approach (reported in D5.5) as well as the baselines for the assessment (D5.4, this report).

The **baseline scenarios** define the situation of the heritage building as starting point for the HeriTACE renovation approach and represent the reference situations of the building for assessing the performance indicators, i.e. to compare the situation 'before' and 'after' a HeriTACE renovation.

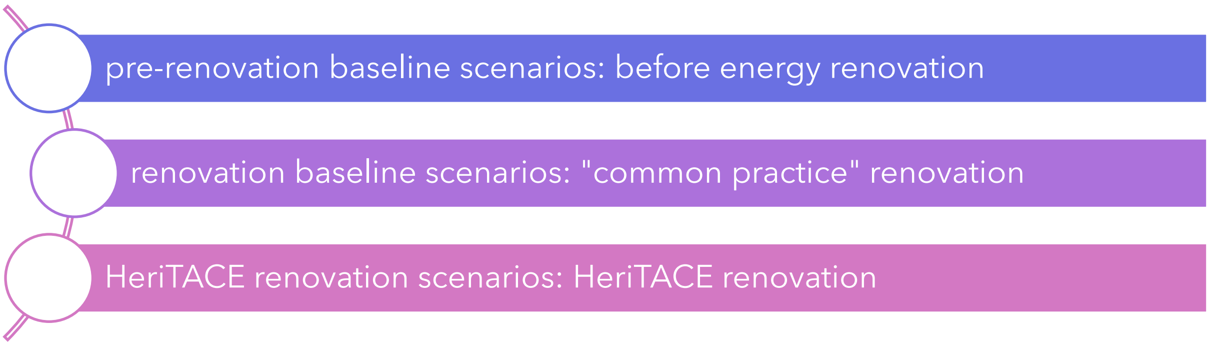


Figure 1: Baseline definition

In this report two baselines are defined for comparison to the HeriTACE renovation approach (Figure 1):

- The **pre-renovation baseline** represents the situation of the heritage townhouse before a renovation takes place. In the HeriTACE project, it is defined as the reference situation of the building as in the *present state, assuming no recent renovation* has taken place to implement a range of recent EPBD-inspired energy renovation measures. This corresponds to the situation of a building in which the last renovation dates from the period 1990-2010.
- The **renovation baseline** documents a *renovation according to common practice today*, where the elements are renovated step-by-step with common practice renovation solutions, and fulfil the local temporary energy-related requirements, such as requirements related to the local EPBD implementations and heritage restrictions.
- The **HeriTACE renovation approach** developed in this project, represents *future-proof renovations* in line with the most recent developments of energy renovations and while maintaining the heritage value. Whether they are executed as a one-step deep renovation, or as stepwise measures, the HeriTACE renovation scenarios provide a complete and optimised plan of energy measures that all together aim at a significant energy use reduction and use 100% fossil-free energy sources in the building and neighbourhood.

The high-level pre-renovation and renovation baseline definitions are applied to the various HeriTACE archetypes by specifying the baseline architectural and use characteristics and building-technical characteristics (Figure 2).

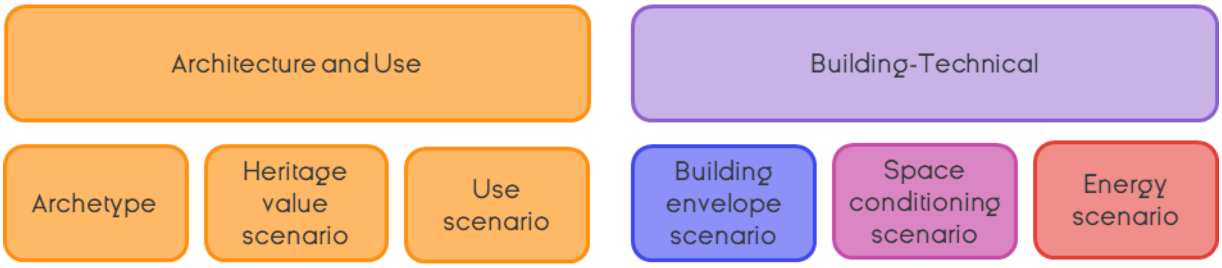


Figure 2: Baseline characteristics

The group of architectural and use characteristics starts with the different heritage townhouse **archetypes**, that were specified per climate-zone (or country) in D5.1, including four Belgian, one Norwegian, four Estonian and four Italian townhouse archetypes.

For each archetype building **heritage value scenarios** are defined, that describe the characteristics of the archetype related to its architectural and heritage value. The heritage value scenarios range from scenarios where the building as a whole has significant heritage value and only limited interventions are allowed (typically applying to a selection of listed heritage buildings), to scenarios for buildings with low or no heritage value, where few restrictions apply. The HeriTACE project mainly focuses on the scenarios in between these extremes, that represent the majority of townhouses with heritage value, where various degrees of restrictions apply with regard to conservation and renovation measures. For each building heritage value scenario, the allowable measures for all building components is specified. In order to apply a uniform approach for the various countries involved, the generalised heritage value categories of allowable measures at building component level, that were defined in collaboration with T5.1 (see D5.2), are applied. These five categories cover the spectrum from very strict conservation (where only conservation measures are allowed) to no heritage restrictions (where any renovation measures are allowed) at building component level.

Furthermore, one or several **use scenarios** can be identified for each archetype, describing the function of the building and user-related characteristics. Townhouses were originally constructed with a primarily residential (single- or multi-family) function, sometimes including secondary small commercial or office functions. This remains the primary use in more recent times as represented in the pre-renovation and renovation baselines, although for some archetypes there are typical changes from single- to multi-family functions, or changes to office or commercial functions. The building user-related characteristics mainly focus on occupation patterns and user behaviour related to the conditioning of the building. For the baseline scenarios, one typical design occupation of the building is chosen per country assuming contemporary comfort requirements that are the result of a typical use and temperature settings for the HVAC systems.

The building-technical characteristics describe the properties of the building envelope, the space conditioning systems and energy systems. As they can also be different for the different archetypes or different heritage value and use characteristics, they are also grouped into scenarios. The baseline scenarios are selected based on the analysis of case-study townhouses in the four countries, combined with literature study, as documented extensively in D2.1, D3.2 and D4.1.

The **building envelope scenarios** document the (mainly energy-related) characteristics of the building envelope, such as the material composition and presence of insulation in walls, roofs, floors and windows, and the air tightness of the building. The pre-renovation building envelope scenarios mostly consist of uninsulated building components, with the exception of the roofs or floors which in some cases have moderate insulation. The main variation is observed in the windows, where, dependent on the heritage value scenario, either original windows and glazing with low energy performance remain, or windows have already been renovated to a medium energy performance in the late 20th century. The overall building air tightness is rather low. The renovation building envelope scenarios mostly apply common practice renovation solutions with contemporary energy performance to the elements with limited heritage restrictions, while elements with higher heritage value may remain original or undergo low energy performance common practice renovations.

The **space conditioning scenarios** describe the heating and cooling emission and distribution system, the ventilation systems and their controls. The pre-renovation space conditioning scenarios either have central heating systems (typically with radiators and operated with room or central thermostats) or still use local heating elements (mostly wood stoves, or electric elements) as in the original buildings usually local heating was applied. In none of the archetypes cooling is applied. In general, no ventilation systems are applied, so the building is mostly ventilated via manual operation of the windows, stack effect and air leakage. In the renovation baseline, the original heat emission systems are mostly maintained. In the Italian archetypes a cooling system is added. In the Estonian and Belgian cases mechanical ventilation systems with heat recovery are installed, and in the Norwegian case mechanical extraction ventilation is applied.

The **energy system scenarios** document the key characteristics of the building energy generation and storage, including systems serving heating, cooling and domestic hot water to the building, the energy storage components and solar energy systems. In the pre-renovation baselines heat is typically provided via central or decentral gas or electric boilers, and/or via local wood stoves. In the renovation baseline, central or decentral gas or electric boilers are still used, but usually more recent higher performance types. In Italy, connection to the district heating grid is also a renovation scenario. Also, in the Italian case, cooling is provided using an air-to-air heat pump. Solar energy systems are mostly not applied, apart from a limited amount of PV installed in the Belgian cases.

The baseline scenarios for the main archetypes will be modelled using multi-zone building energy simulation (BES) models, verified by means of IEQ and/or energy measurements in the case study buildings (see D3.2), and assessed using the project KPI (see D5.5), in the "Baseline BES-models" report D3.3.

While the baseline scenarios are documented in this report, the state-of-the-art and innovative solutions applied in the HeriTACE renovation approach for the various building components are documented in D2.2 (building envelope solutions), D3.1 (space conditioning solutions) and D4.1 (energy system solutions). Optimised combinations of these solutions will assemble into the HeriTACE renovation scenarios, as the HeriTACE research and development, design and modelling tasks are proceeding. They will be modelled and assessed and compared to the baseline scenarios in the D3.8, D3.9, D4.7 and D4.9.

Finally, the baseline scenarios are also the reference point for assessments in the multi-dimensional model for holistic and multi-scale assessment of heritage buildings, that is developed in WP5 and reported in D5.7 and D5.8.

Abbreviations and acronyms

Acronym	**Description**
BES	Building Energy Simulation
DHW	Domestic Hot Water
EPBD	Energy performance of Buildings Directive
EPC	Energy Performance Certificate
EC	European Commission
EU	European Union
GHG	Greenhouse gas
HeriTACE	Future-proofing Heritage Buildings by Optimising Comfort and Energy in Time and Space
HV	Heritage Value
HVAC	Heating, ventilation and air conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
KPI	Key Performance Indicator
MVHR	Mechanical Ventilation with Heat Recovery
RES	Renewable energy sources
R^2ES	Renewable and residual energy sources
WP	Work Package
WPL	Work Package Leader
WWII	World War II

Acronyms used for specifying the scenario's in this deliverable:

e.g. BS1_PB = Building Envelope scenario 1 for the Pre-renovation Baseline

Acronym	**Description**
BS	Building envelope Scenario
CS (or SC)	space Conditioning Scenario
ES	Energy system Scenario
HV	Heritage Value scenario
PB	Pre-renovation Baseline
RB	Renovation Baseline

1. Introduction

A key objective of the HeriTACE project is the development of a holistic and multi-scale integrated approach for the deep renovation of heritage townhouses, that allows to reduce the overall building energy demand by 60% and prepares the building for a fossil-free energy supply. This task (T5.2) defines the holistic set of performance indicators that are assessed within this approach (reported in D5.5) as well as the baselines for the assessment (D5.4, this report).

The baseline scenarios define the situation of the heritage building as a starting point for the HeriTACE renovation approach and are a reference situation for assessing the performance indicators. Two baselines are defined: a pre-renovation baseline and a renovation baseline. The *pre-renovation baseline* represents the situation of the heritage townhouse before a renovation takes place. The *renovation baseline* documents a renovation according to common practice today. Sections 2.3.2 and 2.3 of the report document the (high-level) definitions of both baselines, that have been agreed with all consortium partners and are common for all archetypes.

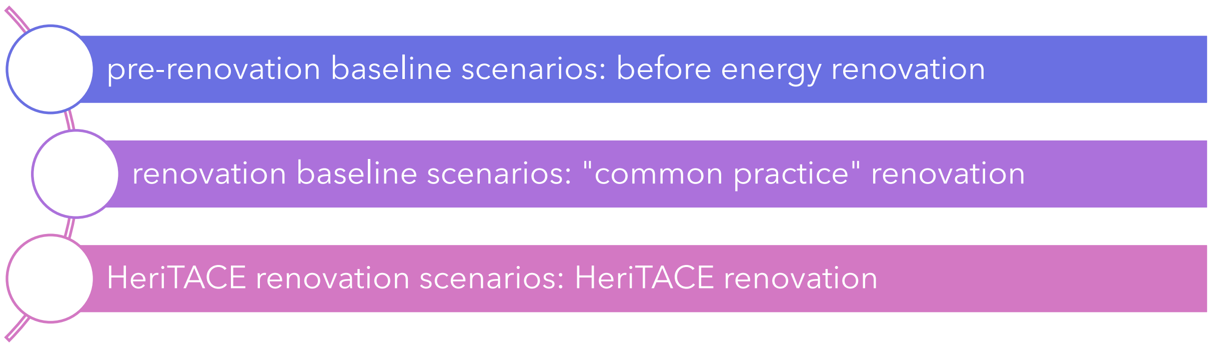


Figure 1: Baseline definition

Besides the (high-level) definitions of the baselines, a more detailed specification of the baseline characteristics is needed, describing the architectural-, use, and building-technical characteristics (Figure). They are introduced in section 2.4 of the report. These characteristics may be different for different archetypes. Therefore the specific combinations of characteristics lead to a range of baseline scenarios, that are specified for each country in the project in chapter 3 to chapter 6.

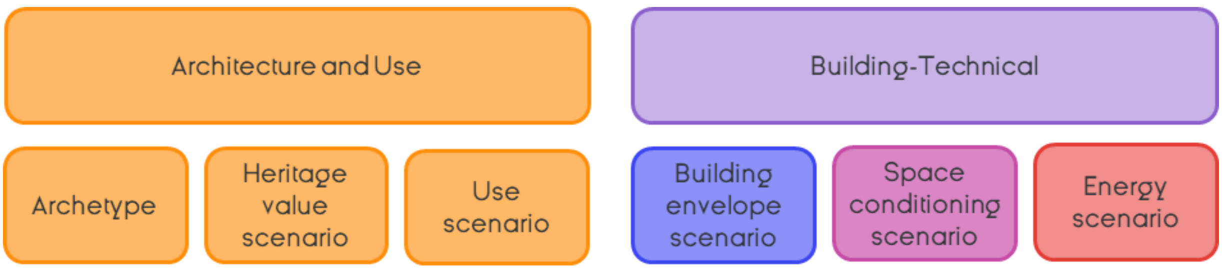


Figure 2: Baseline characteristics

2. Baseline definitions

2.1. Building energy renovation

Buildings are renovated for various purposes: renovation of damaged building elements and constructions (e.g. as identified during routine maintenance activities), adapting the building to changing functions (e.g. from dwelling to office space), adapting the building to changing user and comfort needs (e.g. addition of bathrooms and/or kitchens through history, changing functions of rooms, changing interior/exterior design and fashion), adapting the building to changing infrastructures and technical systems (e.g. change from local to central heating systems, connection to energy, water and sewage networks…), improving the energy-efficiency and indoor environmental quality (IEQ) of the building (e.g. addition of insulation measures, HVAC and R²ES).

As the HeriTACE project aims at future-proofing heritage townhouses for the clean energy transition, the main focus is on renovations that significantly affect the building energy use. Energy renovations evidently influence the energy use, but for example also a change in the use of the building can have a significant impact on the energy use and on which energy renovation solutions can be applied.

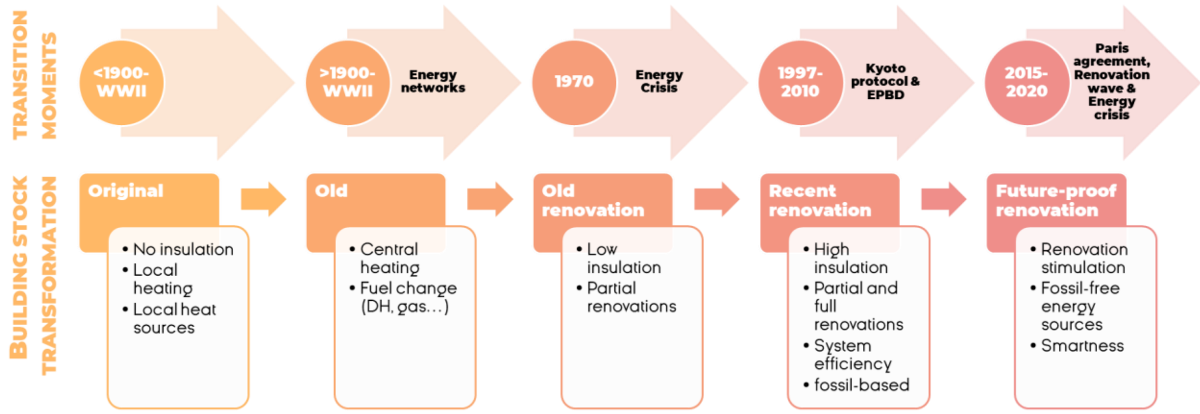


Figure 3: Energy transition moments in Europe

The historical townhouse archetypes studied in this project, were built between the 13th century and mid of the 20th century in various European countries (as documented in D5.1). During their lifetime, various energy related transitions of the overall building stock took place, in which they may (or may not) have taken part. Figure 3 provides a high-level overview of big transition moments in Europe's recent history, and how they initiated transformations of the overall building stock.

- Historical buildings pre-dating 1945, the period in which most of the buildings studied in the project were built, generally had no additional interior or exterior insulation measures in the building envelope. Natural and passive measures were applied to improve the comfort and IAQ in the building (e.g. opening of windows, use of curtains and shutters to keep the warmth inside or outside). The buildings were climatised using local heating systems, such as stoves or fireplaces. The heat was mainly supplied by local energy sources such as coals or wood.

- While the first examples of energy networks in the EU date from around 1900 (mostly starting with electricity networks that would bring light into the buildings), the large-scale installation of district heating and natural gas networks started after 1945. Gradually the fuels of local heating systems changed, and more and more central heating systems were installed. In the same period, the installation of water networks and increased attention for hygiene and comfort, led to the installation (or internalisation) of bathrooms (with hot water supply) in the houses (either as a new construction added at the backside of the house, or in a room which previously had another function).
- The energy (oil) crisis in the 1970s brought attention to the reduction of energy use for geo-political reasons that caused high energy prices. This led to more energy-efficient energy conversion systems and the first introduction of modern insulation measures, albeit with relatively low insulation quality (as compared to today) and applied in few building elements (e.g. roof insulation).
- The IPCC's First Assessment Report on climate change in 1990 stated the impact of human activities on global warming and was the basis for the creation of the UNFCC in 1992. The increased awareness of the impact of fossil energy sources on climate change led to an increased attention to energy-efficiency measures and the reduction of greenhouse gas emissions. In Europe, the Energy Performance of Buildings Directive (EPBD, first version Directive 2002/91/EC) started the framework and requirements for the energy performance of buildings, resulting in increasing insulation measures and quality, energy-efficient (mostly fossil-based) energy systems and attention for the ventilation of buildings. While at first the legal frameworks were mainly addressing new buildings, also in existing buildings insulation measures would be gradually applied to the renovated components. Often exemptions apply for heritage buildings or building components.
- In the most recent period, the Paris Agreement, the Renovation wave, the recent energy crisis and EPBD revision, continue the energy-efficiency measures from the previous period, but emphasise the renovation of existing buildings, the use of fossil-free and R^2ES systems, and smart and flexible energy use.

Note that while Figure 3 provides an overview of transition moments in the broader European context, regional and local variations occur in how they materialise in the building stock transformation. Also, transformations are most easily applied in new buildings, while the transformation of the existing building stock typically takes more time. Sometimes energy-related renovations are the main goal of a renovation (e.g. placing a new heating system because the previous one is broken), but very often they are the by-product of other renovations (e.g. insulating the roof when renovating the attic to become a bedroom). Moreover, full building renovations are less common than stepwise renovations (measure by measure), for practical and financial reasons. In heritage buildings, that have to deal with the complexity of the preservation of valuable elements, the aforementioned observations are even more valid: partial renovation interventions are very common, renovations may have lower energy-efficiency than in regular buildings, and the adoption of new energy-efficiency measures happens slower. This is illustrated in the interdisciplinary analysis of case-study heritage townhouses, that is reported in D2.1, D3.2, D4.1, D5.2 and D5.3 of the HeriTACE project. These studies serve as a complement and background to this report.

The HeriTACE renovation approach developed in this project, are future-proof renovations in line with the most recent developments. Whether they are executed as a one-step deep renovation, or as stepwise measures, the HeriTACE renovation scenarios provide an optimised and balanced plan of energy measures that combined together aim at a significant energy use reduction and use 100% fossil-free energy sources in the building and neighbourhood. They are obtained using the HeriTACE holistic renovation approach that accounts for:

- the *heritage value* of the building and its *durable and high-quality preservation* for the future generations,
- the *indoor environmental quality* to realise a *healthy and comfortable* environment exactly where and when the users need it, ensuring better living conditions,
- the overall *energy-efficiency* of the heritage building and its readiness to decouple from fossil fuels;
- the increased and smart *use of Renewable and Residual Energy Sources* in the building and its improved integration in the local energy grids
- the overall *sustainability*, efficient and circular material use, reducing the renovation environmental impact;
- the increased life-time *cost effectiveness* and affordability

To achieve this, the renovation approach integrates and optimises solutions at three scales: the building and system components (building envelope, HVAC and R²ES components), the building, and the neighbourhood. Well-considered and targeted measures at each of these scales are part of an optimisation over all the scales.

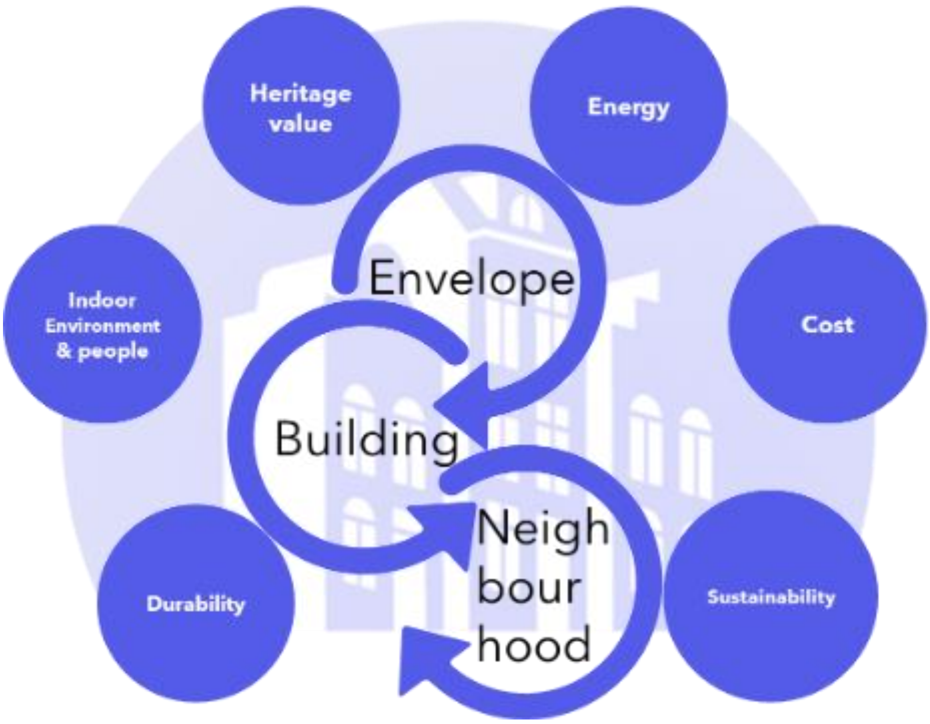


Figure 4. Concept of the HeriTACE holistic and multi-scale renovation approach

In the next sections, the pre-renovation and renovation baseline concepts are defined.

2.2. Pre-Renovation baseline

The pre-renovation baseline represents the situation of the townhouse *before a renovation* takes place. However, the heritage townhouses studied often have gone through various (light or deep) renovations and maintenance activities during their lifetime so far. The question raises to which moment in the lifetime of the building do we refer as a pre-renovation baseline? Would it be the original situation of the building? Or if not, which changes and renovations are included in the baseline?

The original situation of the building would be interesting to study from a historical perspective to document and learn how comfort used to be obtained in past era's, what comfort levels used to be reached, and with how much energy use and GHG emissions this would have come. Some of the heritage townhouses studied still use some of the original techniques, such as local heating to heat only parts of the building, or passive measures to improve comfort (curtains, window shutters, natural ventilation…). Some of these solutions still are an inspiration for modern approaches studied in the project, such as ventilative cooling, use of shading, or sufficiency measures.

However, the interdisciplinary case-study analysis and the reflections in section 2.1 illustrated that heritage townhouses often already went through some renovations, and also the user perspectives (how people live and behave, the comfort and IEQ they expect) have changed and scientific insights and standards (e.g. regarding IAQ and comfort) have evolved. Therefore, the original performance of the building may be quite different from its performance in more recent times and using it as a baseline would not provide us with a good insight on actual performance improvement.

There are several arguments in favour of a more recent building situation as pre-renovation baseline. First, the performance improvements would be compared to a recent reference. For example, regarding energy and GHG emission reductions, also climate goals are expressed as compared to recent references (between 1990 with the IPCCs first report on climate change, and today). Secondly, the use of the building, the comfort and IEQ expectations would be close to today's needs and standards (e.g. houses would have a bathroom inside). Thirdly, residential buildings (which is the main building function studied) are renovated on average every 20-30 years. Therefore, buildings that have not gone through a deep renovation in recent years are a relevant reference. Finally, the case-study analysis in the different countries has shown that the situation in which heritage townhouses that have not been recently renovated, are found today, often corresponds to a situation referred to as the 'old' (or 'recent') renovation in Figure 3. They have been little influenced by the requirements raised in the implementations of the EPBD. For example, in the case-studies, we see that central heating systems with relatively efficient fossil-based boilers would already be installed, but only few parts of the building would be insulated, and typically not to the insulation standards used today.

Therefore, as a pre-renovation baseline, the reference situation of the building as in the present state is chosen, assuming no recent renovation has taken place to implement a range of recent EPBD-inspired renovation measures. This corresponds to the situation of the building after some 'old renovation' measures, as would have been done during a renovation in the period 1990-2010.

In the next chapters, the pre-renovation baselines for each country and archetypes are described more in detail.

2.3. Renovation Baseline

The renovation baseline corresponds to a renovation according to *common practice today*. In practice we mostly observe stepwise (or elementwise) renovations of the building, where the various elements are renovated with common practice renovation solutions, and fulfil the local temporary energy-related requirements. For example, these are requirements related to the local EPBD implementations or other energy-related legislation, and taking into account exemptions that may apply for buildings or specific building components with recognised heritage value. The local context and implications for the renovation baseline are explained for each country in the following chapters.

2.4. Characteristics of the baselines

When implementing the high-level definitions of the pre-renovation and renovation baseline to the heritage townhouse archetypes, different characteristics need to be addressed. While the (high-level) definitions are uniform for all HeriTACE archetypes and regions, the specifications depend on the local historical and present contexts.

Figure 5 shows the various characteristics. The group of architectural and use characteristics starts with the different heritage townhouse archetypes, that were specified per climate-zone (or country) in D5.1. For each archetype one or multiple heritage value scenarios is defined, that describe the characteristics of the archetype related to its architectural and heritage value. Also, one or several use scenarios can be identified, describing the function of the building and user-related characteristics. The building-technical characteristics describe the properties of the building envelope (e.g. construction and materials), the space conditioning systems (heating and cooling emission and distribution system and ventilation system) and energy systems (the energy storage and generation systems). As they can also be different for the different archetypes or different heritage value and use characteristics, they are also grouped into scenarios.

Each of the six characteristics is introduced more in detail in the following sub-sections. Then, in the subsequent chapters, the characteristics are specified per country for each archetype. In order to clarify the combinations of characteristics scenarios, each chapter starts with a schematic overview.

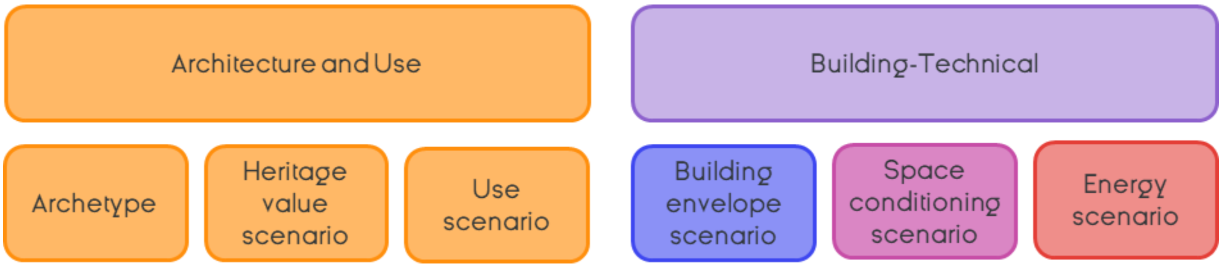


Figure 5: Baseline characteristics

2.4.1. Archetype

The HeriTACE project focuses on small to medium-sized heritage townhouses as a building type. Because of the diversity in the design of heritage townhouses through time and in various places in Europe, representative archetypes have been identified for the heritage townhouses studied in the different climate regions and historical periods that are in focus in the project.

An archetype is a typical and often repeated principle of a building design with clear characteristics. It serves as a prototype for designing buildings with the same function. The archetype describes the key architectural features (formal characteristics, dimensions, spatial organisation…). It is basically documented in architectural drawings such as plans, sections and elevations. An archetype differs from a case-study, which is a real-life building that is a variation or adjustment of the archetype to a specific context in which it is built.

The archetype-approach ensures the replicability of the renovation strategies developed in the HeriTACE project for the variety of buildings of the same archetype. The selected townhouse archetypes are extensively documented in project deliverable D5.1. In this baseline definition report, an overview of the archetypes per country is provided.

2.4.2. Heritage Value scenarios

The cultural heritage value of a historic building covers a wide range of values of the building, including architectural, aesthetic, historic, cultural, scientific, experiential, social and other values. The values are assessed by conservation experts performing a cultural heritage analysis of buildings in the present time within the present conservation discourse. The value assessment provides the basis for identifying which interventions are allowable for the various building elements while preserving their peculiarities, in accordance with the assessed values and the analysed conservation status. The cultural heritage analysis and value assessment methodology is explained in project deliverable D5.2, where it is also applied to case-study buildings for each of the HeriTACE archetypes.

The outcome of a cultural heritage analysis is case-specific, and thus different cultural heritage values can be observed within the townhouse typology. Moreover, local differences in the conservation discourse may lead to subtle differences in the conservation and renovation advice. This challenges the HeriTACE ambition to develop replicable renovation strategies for the archetypes. Therefore, two steps of generalisation were developed with the conservation experts involved in the project. A first step was to agree on common categories (for all countries involved) that express which interventions are allowed when considering a historic building. These categories apply at component level (see Figure 6). As a second generalisation step, the local experts developed baseline heritage value scenarios (HV) at building level, in which each time the categories of allowable measures are specified for the building components (focussing on the components that could be impacted by energy-related renovation of the building). These were based on experts' knowledge of the cultural significance of analysed archetypes and on the detailed analysis of the HeriTACE case studies. Hence, the resulting heritage value scenarios represent typical situations, as the basis for developing baseline and HeriTACE renovation solutions that respect the heritage value. For the majority of cases within the archetypes under study, a 'close-by' heritage value scenario could be identified. The heritage value scenarios at building level are documented per country in the consecutive chapters.

Figure 6 provides an overview of the categories of allowable measures at component level when considering cultural heritage value. The five categories cover the spectrum from very strict conservation ("zero"-category) to situations where no value restrictions apply (category 4). In D5.2 a more extensive explanation and examples for each category are provided.

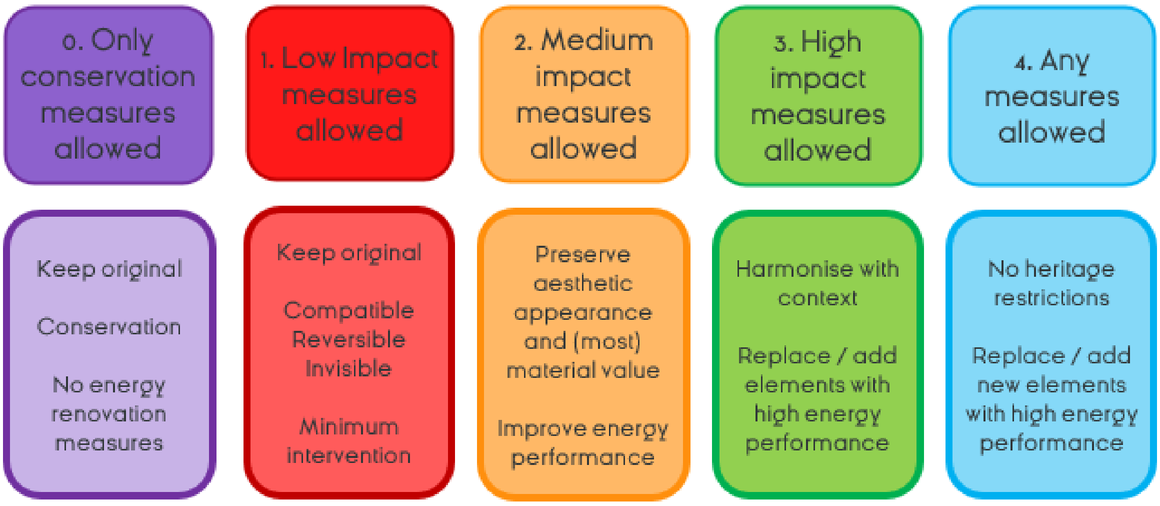


Figure 6: Categories of allowable measures at building component level considering cultural heritage value

Category 0: Only conservation measures allowed

In this category only conservation activities are possible. As explained in the Venice Charter and the UNESCO glossary, conservation related to buildings involves a range of actions to maintain, protect, and manage change to heritage assets or listed buildings (Piero Gazzola et al., 1964; UNESCO Institute of statistics, 2020). This means that in this category, measures applicable from maintenance to restoration of the existing elements are included. However, as any measure could induce damage risks to the building, a careful consideration is needed before the decision-making. Restoration would also be recommended if it is considered necessary to remove components that are not coherent (e.g. recent additions or inadequate adaptations to the building), in order to re-establish a more historically correct situation. In this category, energy-related improvements to the building component are not allowed, as they would have impact on the authentic material, form, or finishes. Any measure, maintenance- and restoration wise, in this category might also induce damage risks to the building and should thus be thoroughly elaborated before implementation.

Category 1: Low impact measures allowed

This category allows low impact solutions requiring minimum interventions. Minimum interventions include interventions that are reversible in the future and/or removable without affecting the authentic materials, form, and finishes in a permanent way or causing decay. Certain energy-related solutions can be included, considering the criteria of minimum intervention, compatibility and reversibility.

Category 2: Medium impact measures allowed

This category allows to provide energy-related improvements to original components, by making additions and/or small and compatible substitutions. The aim is to preserve the existing historic elements with their material value as much as possible, as well as maintaining the overall aesthetic appearance of the building components. Hence, the allowed solutions avoid for example huge holes, drillings, demolitions, and dismissions of elements. This category may also apply in situations where previously made erroneous changes (e.g. inappropriate regarding heritage value or technically damaging) require reversion to a situation that is close to the original (e.g. same material and design), but with an improved energy performance as compared to the original situation.

Category 3: High impact measures allowed

In this category, it is possible to remove existing elements and replace them with new ones. No historicising replacement is envisaged, but the new elements must harmonise with the surrounding materials and context. In this case, the existing elements have low heritage value, they date from a later construction phase that does not harmonise with the surrounding materials and context, or they are too damaged to enable a repair. This is only possible if the heritage protection status of the building does not require restoration to the original model or the preservation of the authentic materials. The replaced components may not alter the overall shape and proportions of the building.

Category 4: Any measures allowed

In this category, no restrictions are imposed from a heritage perspective. Although substitutions of materials, shapes or finishes should not be done according to original model or should not refer to an original version, the structure of the building cannot be altered (no new window openings, no new floor structure, …)

2.4.3. Use scenarios

The building use covers a range of aspects as discussed in D5.3. For the baseline scenarios, the energy-related use aspects are identified. The most influential aspect is the function of the building, as it determines occupation and the distribution of functions across the rooms. Additionally, IAQ and comfort are included under the use scenarios.

Building function

Heritage townhouses generally were designed with a primary residential function, as a single- or multi-family dwelling. Each archetype design was originally made for a certain class in the society, examples are the artisan and labourers single-family houses in the Norwegian archetype and multi-family buildings in the Estonian archetypes, to the Italian and Belgian middle-class and high-class townhouses. Sometimes, the heritage townhouses incorporated secondary functions such as small-scale commercial or office functions.

Over time, some archetypes changed function, for example the larger archetypes (e.g. the private mansion or courtyard building archetypes) often do no longer correspond to contemporary living needs and are transformed into multi-family housing or office-, business-, or commercial spaces. In the project, few typical and often occurring function changes are accounted for in the renovation baselines.

Occupation, comfort and temperature settings

Apart from an actual change in building function, how the building is used (within its overall function) also changed over time: people's activities at home and how much time they spend at home evolve over time. In some (historical) buildings 'underuse' of the building is observed, where the contemporary occupancy is much lower than the design occupancy. Also, the users' needs and wishes in terms of comfort and IAQ change, as a consequence of evolutions in home activities, clothing uses, availability of energy sources and evolving technical systems.

Moreover, differences in user behaviour led to very different comfort and IAQ in dwellings, as illustrated in the case-study analysis report D3.2. This energy-related user behaviour has an important impact on the energy performance of the building and explains a lot of the variability in energy use of buildings of the same archetype. Within the project, the effect of different user behavioural strategies, including 'sufficient' user behaviour, will be accounted for when studying the HeriTACE renovation scenarios. However, as a baseline, *one typical design occupation of the building* is selected. It has a typical occupation that fits the design of the building, combined with contemporary comfort requirements that are the result of typical use and temperature settings for the heating and cooling systems. The baseline comfort and temperature settings are the same for the pre-renovation and renovation baselines, but they may differ for archetypes in the different climate zones. The design occupation and temperature settings per climate zone are summarised in the next chapters of this report, while a more extensive motivation is provided in D3.2 based on observations in the case-study heritage townhouses and relevant standards.

2.4.4. Building envelope scenarios

The building envelope scenarios document the energy-related technical characteristics of the building envelope, such as the material composition and presence of insulation in walls, roofs, floors and windows. Additionally, the airtightness of the building is established. In D2.1 the building envelope characteristics are documented in detail for the different heritage townhouse archetypes, based on the analysis of case-study buildings and documentation from literature. The choice of baseline scenarios is also concluded there. The baseline definition report provides an overview of the building envelope scenarios with a high-level description of the composition of the envelope elements.

2.4.5. Space conditioning scenarios

The space conditioning scenarios document the key characteristics of the space conditioning systems in the building. These include the ventilation solutions, and the heating and cooling solutions with focus on the emission, distribution and control elements. D3.2 includes an inventory of the systems observed in the case-study buildings as a reference for these choices, alongside a more elaborate description of the baseline systems.

2.4.6. Energy scenarios

The energy scenarios document the key components of the building energy generation and storage systems. They include the solutions for providing heating, cooling and domestic hot water (DHW) to the building, the energy storage components and solar energy systems. D4.1 includes an overview and motivation of the selected energy systems.

3. Belgium: baseline scenarios

3.1. Overview

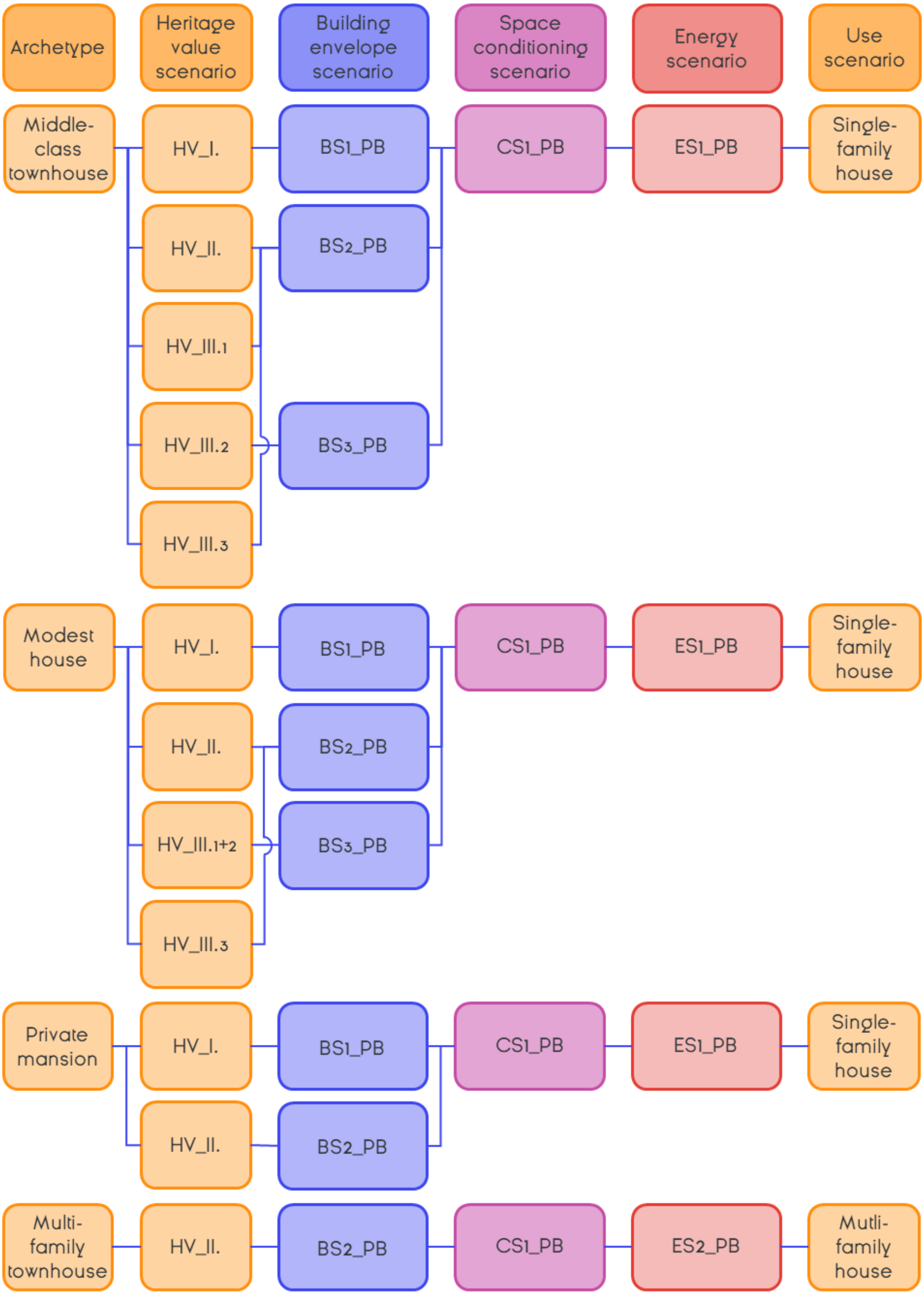


Figure 7: Overview of the pre-renovation baseline scenarios (BE)

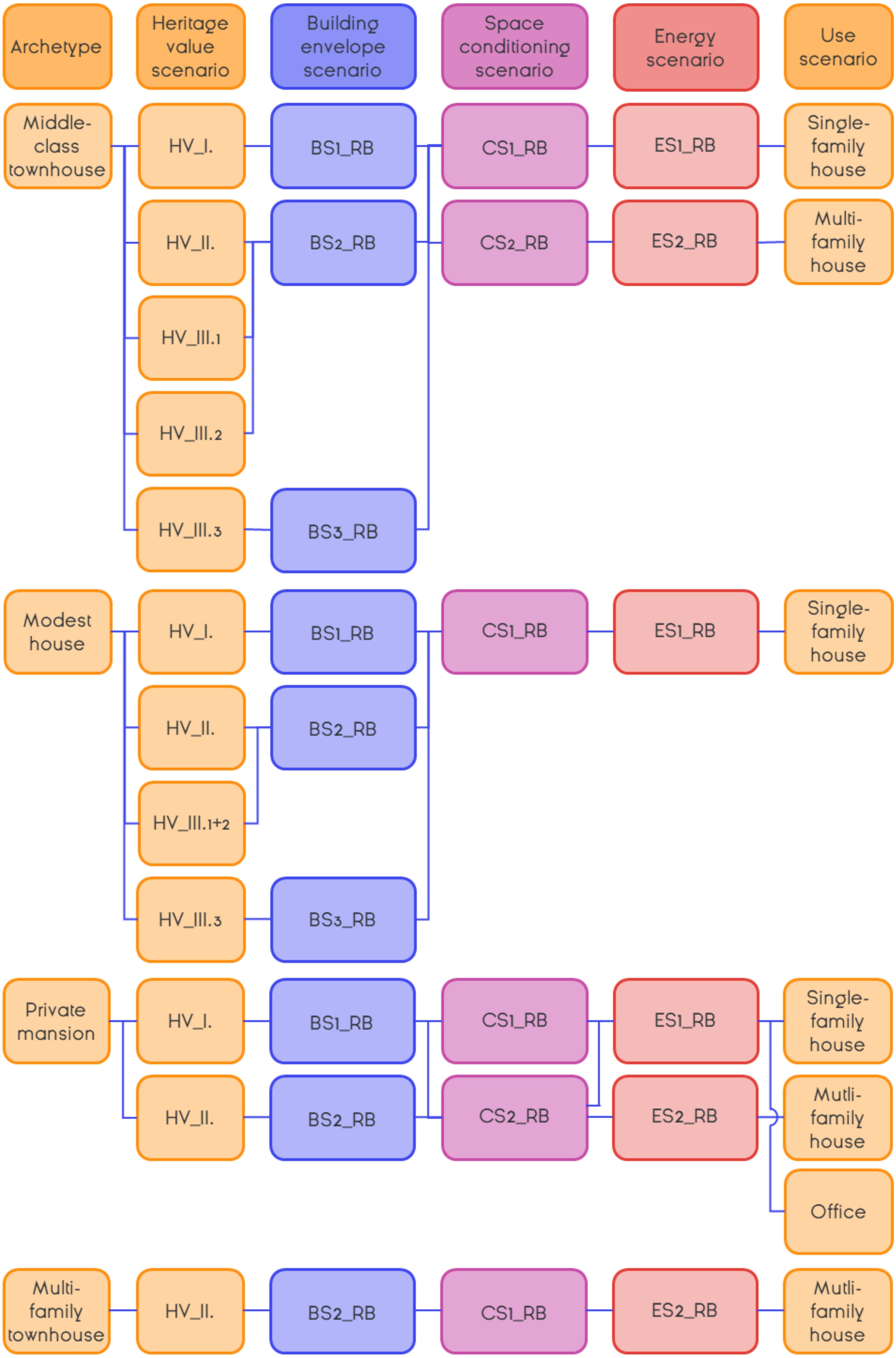


Figure 8: Overview of the renovation baseline scenarios (BE)

3.2. Archetypes

Middle-class townhouse Modest house Private mansion Multi-family townhouse

Figure 9: Overview of townhouse archetypes by facade (BE)

In Belgium the typology of the heritage masonry terraced townhouses, built between 1800 and 1918 is studied. During this period of industrialisation, historical cities in Belgium and other major EU cities, experienced a colossal growth and the bourgeois society emerged. The townhouses reflect the evolving social landscape of this bourgeois society. They were shaped by the desires for individuality and social status, leading to distinct architectural forms, especially in their facades, which became key to personal expression and were thus highly ornamented. Other common features among all the typologies include a vertical organization and a clear hierarchy of spaces, arranged as an enfilade perpendicular to the street and on top of each other. The **middle-class townhouse** is most prevalent in all Belgian historical cities and certainly in Ghent. Wealthier homes, the **private mansions**, present an excess of rooms, more elaborate spatial divisions and more decorated facades and interiors. **Multi-family townhouses**, although less prevalent in Ghent, are common in bigger cities like Antwerp and Brussels, where they maintained the hierarchical structure of middle-class living but with a horizontal organization, reflecting a shift from verticality to internal differentiation. In contrast, **modest houses** represented a simplified version of middle-class townhouses, with fewer rooms and less complexity, tailored for the upper working class.

3.3. Heritage value scenarios

Five heritage value scenarios were identified for the Belgian townhouse archetypes (see Figure 10), ranking from scenario HV_0 with the highest heritage value to HV_IV without heritage value. The HeriTACE project focuses on the HV_I – HV_III scenarios, that are the most representative and replicable for the heritage townhouse archetypes. In Figure 10, for each heritage value scenario, the building sections indicate the heritage value categories (as explained in section 2.4.2) that apply to each building component. The section of the middle-class townhouse is used as example.

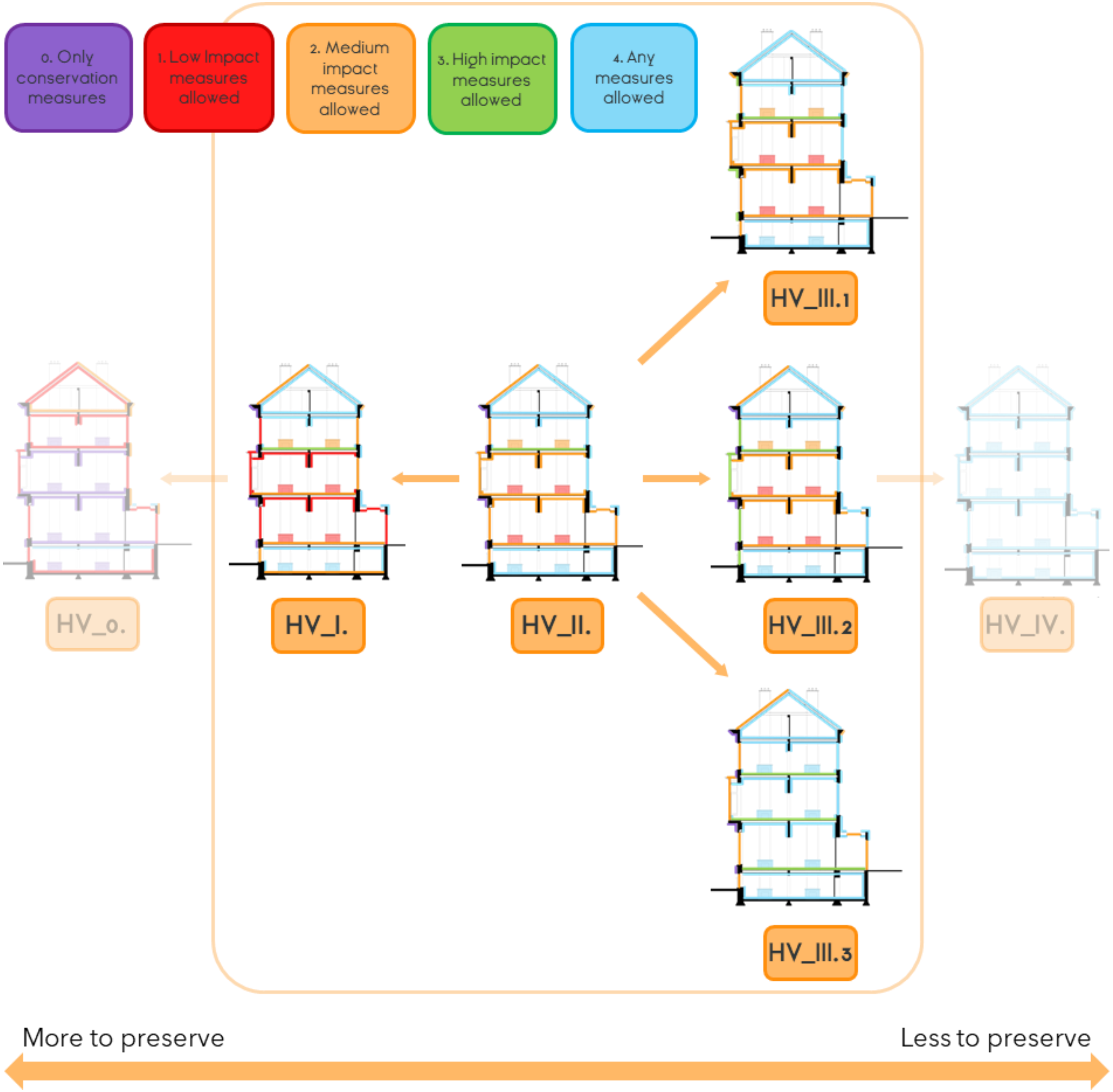


Figure 10: Overview of heritage value scenarios (BE)

HV_0. Highly valuable building as a whole

The building as a whole has significant heritage value, and few alterations have been made throughout its history. Therefore, the building envelope and interior must be entirely preserved, and only limited interventions are allowed (Category 0 and Category 1 apply to most elements).

This heritage scenario primarily applies to listed buildings, which are legally protected by a ministerial decree. While all four archetypes could potentially be listed as a monument or cityscape, this scenario is found mostly in private mansions and middle-class townhouses. This heritage value condition will not constitute the central focus of the HeriTACE project.

HV_I. Highly valuable facade, windows and interior

In this highly valuable scenario, the entire front façade is of high value and the windows in the front façade cannot be changed because of their recognised heritage value or because they are found valuable by the owners or designers. The back façade as a whole has low heritage value; however, certain windows should be retained because of their impact on the interior. A valuable interior is present on the bel étage and the first floor: walls, ceilings and valuable elements such as fireplaces, mantelpieces, panelling, mouldering ceilings etc. are to be preserved, but small interventions are possible. Interventions in floor elements are also possible provided the floors are restored. The interior from the second floor and above is less valuable.

This heritage value scenario is applicable for the private mansion and the middle-class townhouse, as they were originally richly decorated and usually better preserved over time. Buildings that are part of a protected cityscape can usually be classified under this heritage value scenario. Highly valuable buildings in the ascertained built heritage inventory in Flanders can be classified under HV_I.

HV_II. Highly valuable façade with typical valuable interior elements

This scenario has a highly valuable facade but with windows that can undergo medium impact interventions (category 2). The back façade and windows have low heritage value. The bel étage and the first floor have some typical valuable interior elements such as fireplaces, mantelpieces, mouldering ceilings, for which only low impact measures (category 1) are allowed. The interior elements from the second floor and above are less valuable.

This heritage value scenario represents the most prevalent situation and is applicable for all four archetypes. The multi-family townhouse is classified only under this heritage value scenario. In practice, this archetype could also be classified under HV_III.2 and HV_III.3 and exceptionally also under HV_I and HV_III.1. Because of the lower presence of this archetype in Ghent/Belgium, only HV_II, the most prevalent HV scenario, is applied.

Most of the buildings included in the ascertained built heritage inventory in Flanders can be classified under this heritage value scenario, and some building that are part of a listed cityscape could be included under HV_II.

HV_III.1 Less valuable facade with valuable windows and interior elements

The façade is less valuable (e.g. a simple plaster façade without any decorative elements or mouldings) so interventions are possible. The windows and certain interior elements are valuable but can undergo small interventions. The entire back façade including the windows have low heritage value. Interior elements on the bel étage are valuable and are treated the same wat as in HV_II. From the second floor on, the interior is less valuable.

This heritage value scenario is applicable for the modest house, as they were usually decorated more simple and also usually less preserved in their original condition. Middle-class townhouses with simple façades or façades that underwent thorough renovations can also be classified under this heritage value scenario.

HV_III.2 Highly valuable facade with low valuable windows

In this scenario, the highly valuable façade cannot be changed, but the windows in the front façade have a low heritage value. Either these windows are too damaged to be preserved, or they have already been replaced by new ones in a different material, or with another layout or details. Certain interior elements still have heritage value and are thus to be preserved (same as in HV_II). The back façade, including the windows, have low heritage value.

This is also a prevalent heritage value scenario. It is applicable to the middle-class townhouse and the modest house. After all, in these archetypes, there are often new windows that no longer have a connection with the original windows due to their choice of materials, different window layout or detailing. The private mansion has often been treated with more respect for the heritage value; therefore this scenario is not applicable for that archetype.

HV_III.3 Highly valuable facade with low valuable interior

This heritage value scenario is characterized by a highly valuable front façade and valuable windows, but where the interior has a low heritage value. The typical interior elements for this type of buildings are removed throughout its history, allowing for more impactful interventions in the interior. The back façade, including the windows, have low heritage value.

This heritage value scenario is applicable to middle-class townhouses and modest houses, as this type of buildings underwent often the biggest changes at the interior side. In contrast, the private mansion often has a richly decorated interior that is preserved until today.

HV_IV. Building without heritage value

This is a scenario for a building with no specific heritage value. This represents a terraced townhouse with the same typological structure (e.g. high storeys, bel étage, traditional plan lay out, etc…), but not specifically valuable. This building can be a modern example of the same archetype or a historic example that has lost all its heritage value during its lifetime (due to an accident, too radical renovation, …) Every archetype can be classified under this scenario, except for the private mansion. This scenario is included in the list for providing a complete overview of scenario's that occur for the considered archetypes but is not in scope of the HeriTACE project.

3.4. Pre-renovation baseline scenarios

3.4.1. Use scenarios

Building use: function

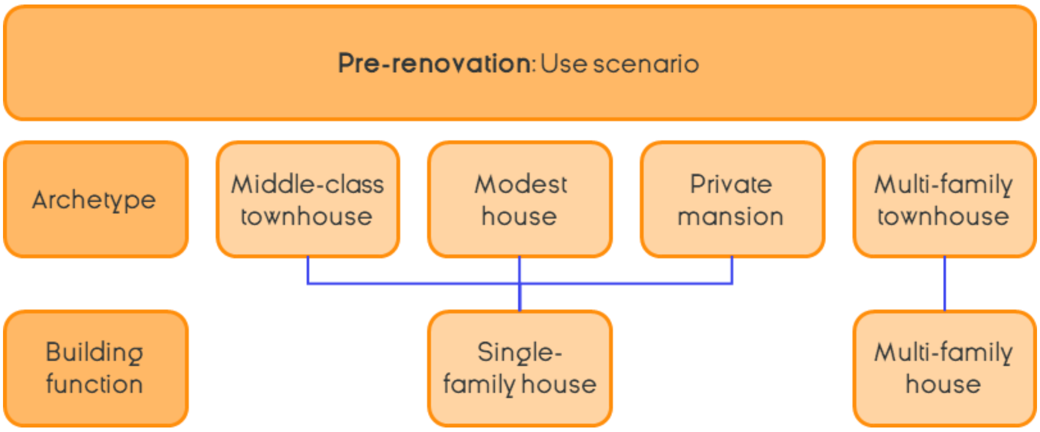


Figure 11: Pre-renovation Use scenario's (BE)

In the pre-renovation baseline, the middle-class townhouse, modest house, and private mansion are all considered single-family dwellings. The attic and basement are generally not in active use and serve primarily as (unconditioned) storage or technical spaces, with the exception of the modest house, where the attic is actively used, usually as bedrooms. This current usage differs significantly from the original function, in which these auxiliary spaces traditionally served as living and working quarters for domestic staff.

The multi-family townhouse, as the name implies, is configured as a multi-family residence, accommodating separate apartments within a single building. In this case as well, both the attic and basement remain unconditioned and unused or used as technical space.

Comfort – temperature settings (heating and cooling)

The living room is heated to 20 °C during the day, with a night setback to 15 °C. As the living room thermostat controls the central heating, this setback applies to the whole house. Thermostatic radiator valves set the temperatures in other rooms: bedrooms are heated to 18 °C, hallways and veranda to 16 °C (the veranda serving as a buffer space in winter). The bathroom is heated to 24 °C only when in use—during morning and evening hours—while maintaining 18 °C at other times.

3.4.2. Building envelope scenarios

Pre-renovation: Building envelope scenario				
Scenario		BS1_PB	BS2_PB	BS3_PB
Walls	Front facade	Solid masonry walls with interior lime plaster and exterior lime plaster		
	Back facade	Solid masonry walls with interior lime plaster and exterior lime plaster		
	Annex facade	Solid masonry walls with interior lime plaster and exterior lime plaster		
Top boundary	Pitched roof	Traditional wooden purlin-supported roof with ceramic tiles Minimum insulation between the rafters		
	Flat roof	Wooden beam structure finished with lime plaster ceiling, waterproofing layer Minimum exterior insulation		
Floors	Basement floor	Tiles in sand bed		
	Basement ceiling	Cement tile flooring on vaults Wooden floor structure with wooden flooring		
Windows	Front windows	Original wooden frame Single glazing	Original wooden frame Single glazing	Double glazed windows
	Back windows	Original wooden frame Single glazing	Double glazed windows	Double glazed windows
Airtightness		$v_{50} = 16\ m^3/hm^2$	$v_{50} = 14\ m^3/hm^2$	$v_{50} = 12\ m^3/hm^2$

Figure 12: Pre-renovation building envelope scenarios (BE)

All Belgian townhouse archetypes are characterised by a masonry construction with mostly wooden floor and roof structures. Dating back from the same building period, the original materials and compositions of the various building envelope components for the different archetypes are very similar. The **walls** (of the front façade, back façade and annex building) are uninsulated solid masonry walls, finished with lime plaster at the interior side. The exterior side is assumed to be finished with lime plaster in the baseline scenario (but in reality, also façade bricks and natural stone finishings are prevalent). The **floor** of the basement consists of cement tiles placed in a sand bed. For the floors of the ground floor two constructions are used: vaulted floors with cement tiles in the hallway, and wooden floors in all other rooms (as well as all the other intermediate floors). In more recent times, the **roofs** have typically been insulated with minimum insulation. The traditional wooden purlin-supported roof is assumed to be insulated between the rafters. Where flat roofs are present (e.g. on the annexes), they comprise of a wooden structure with limited exterior insulation and a waterproofing layer. Also, the **windows** often underwent changes in the more recent past, however how they have been changed is influenced by their heritage value. Therefore, three pre-renovation building envelope scenarios were defined, related to different heritage value scenarios, and that only differ in terms of the properties of the windows, and (as a result of those) the air tightness of the building.

BS1_PB: Low insulated building with all original windows

In building envelope scenario 1, the windows in the front façade and the back façade are still the original wooden frames (with their distinctive appearance) with the original single glazing. This scenario is typical for townhouses with high heritage value (HV_I): because of their high heritage value, the windows are still original in the pre-renovation state of the building. Because of these old windows and the possible associated cracks, crevices and wear, the airtightness of this scenario is considered the worst of the three, with an average envelope v50-value of 16 m^3/hm^2.

BS2_PB: Low insulated building with only original windows in the front facade

Building envelope scenario 2 is the most prevalent scenario and relates to heritage value scenario's HV_II, HV_III.1, and HV_III.3. In this scenario, it is assumed that the windows in the back façade have already been replaced throughout the lifetime of the building. It is assumed they are replaced by contemporary windows at the time of a previous renovation (e.g. in the period 1990-2000), that is: new window frames (often in PVC or wood) with double glazing. The windows in the front façade are still the original wooden frames with the original single glazing. Because of the replacement, and the associated supposed attention for airtight finish, the airtightness of this scenario is better than BS1_PB, with an average envelope v50-value of 14 m^3/hm^2.

BS2_PB: Low insulated building with all double-glazed windows

Building envelope scenario 3 is applies to HV_III.2 scenario. The windows in the front façade and the back façade are supposed to be already replaced by contemporary windows at the time of a previous renovation (e.g. in the period 1990-2000), that is: new window frames (often in PVC or wood) with double glazing. Again, the replacement of old windows by new windows and the associated attention for airtightness, makes it that this scenario has the best airtightness of the three scenarios, with an average envelope v50-value of 12 m^3/hm^2.

3.4.3. Space conditioning scenarios

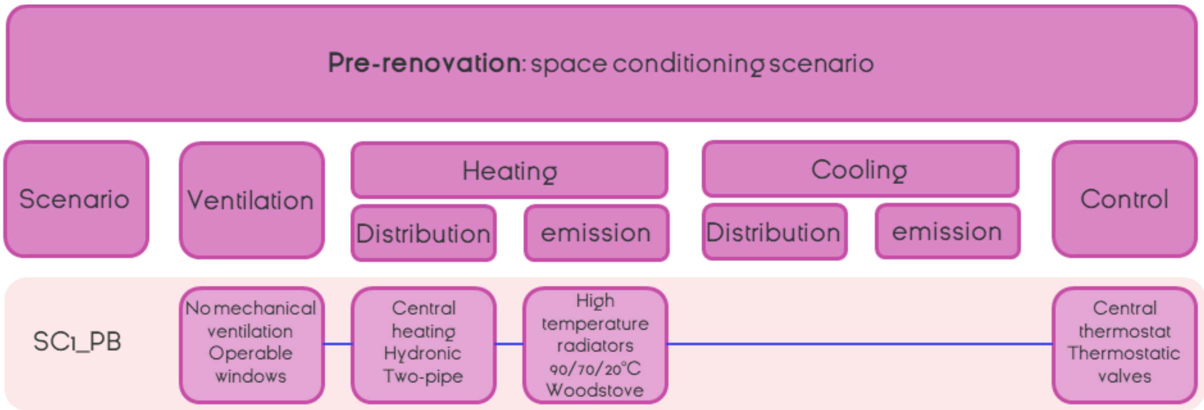


Figure 13: Pre-renovation space conditioning scenario (BE)

The pre-renovation baseline for space conditioning is consistent across all building archetypes. A central hydronic heating system is assumed. High-temperature radiators (designed for a 90/70/20°C regime) are provided in each heated room. The heating system is controlled by a central thermostat placed in the living room, that operates on a conventional on/off control logic. Thermostatic radiator valves on the radiators in all other rooms, allow localized temperature control. No mechanical cooling or central ventilation system is present. Indoor air quality is maintained through manual opening of windows by the users. A range hood in the kitchen is present.

3.4.4. Energy scenarios

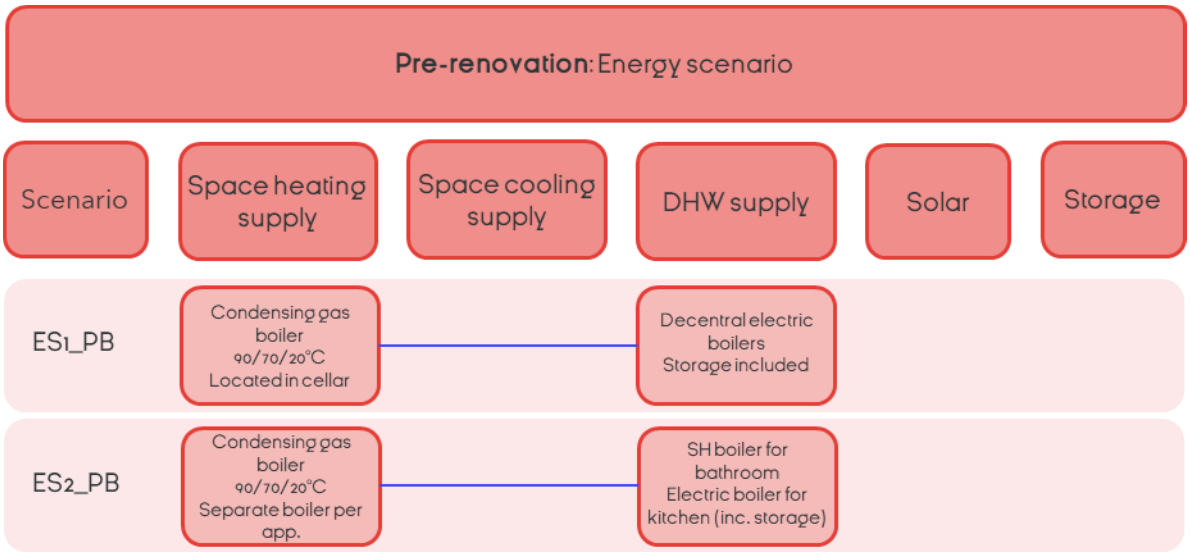


Figure 14: Pre-renovation energy scenarios (BE)

In the original situation, the townhouses used to be heated by use of local fireplaces or stoves in the main rooms and use stoves for cooking and hot water production in the kitchen. In the course of the 20th century, most of these buildings have been equipped with central space heating systems and are connected to the natural gas grid. Also, bathrooms (with DHW) were installed within the building. Sometimes, the fireplace or stove in the living room is still present, to be used as additional comfort heating.

ES1_PB: Gas boiler, electric DHW boilers

The first energy scenario is applicable to the middle-class townhouse, the modest house, and the private mansion. In this configuration, space heating is provided by a condensing gas boiler with low efficiency, that is located in the cellar and produces heat at 90°C for space heating purposes. DHW is generated locally at the tap points through separate electric boilers installed in the bathrooms and kitchen, each equipped with integrated storage to ensure adequate hot water supply. No cooling system is included in this scenario, nor is there any provision for energy storage or the integration of solar energy systems.

ES2_PPB: Gas boiler per app., electric DHW boilers

The second energy scenario is exclusively applicable to the multi-family townhouse archetype and differs from the previous scenario primarily due to the presence of multiple residential units within a single building. In this configuration, each apartment is equipped with its own condensing gas boiler with low efficiency, operating with a supply temperature of 90 °C for space heating. DHW for the bathroom is also produced by the same gas boiler within each unit. However, in the kitchen, DHW is supplied by a dedicated electric boiler with integrated storage. As with the first scenario, no mechanical cooling system, energy storage, or solar energy technologies are included.

3.5. Renovation baseline scenarios

The renovation baseline corresponds to a renovation according to *common practice today,* that fulfils the local contemporary energy-related requirements. For Ghent and the Flemish region in Belgium, the Flemish energy regulations for existing residential buildings applies (Flemish Heritage Agency, 2025). The main regulations relevant for (heritage) buildings are:

1. The obligation to have an Energy Performance Certificate (when selling/renting the dwelling) that states the energy performance of the building (however with no specific minimum requirement)
2. The renovation obligation, now specified as: to renovate dwellings to EPC label D within 5 years after a change in ownership
3. Minimal living quality standards (mainly for dwelling in rental), including minimal roof insulation and double-glazing requirement
4. The EPBD requirements when doing a building renovation that requires a building permit: high insulation and technical installation requirements, mainly for the renovated parts of the building (in case of renovation), high overall energy performance requirements (in case of a whole energy renovation of the building).

However, for the renovation of buildings of which the heritage value is officially confirmed (that is: buildings included on the ascertained architectural heritage inventory, buildings in a listed cityscape and listed monuments), there are some exemptions. The legislation provides a detailed description of what exemptions are possible in the various situations, however the main principle is that exemptions apply to those parts of the building that contribute to the officially recognised heritage value (e.g. for a building in a listed cityscape, exemptions may apply to all parts of the building visible from the public domain, while other parts of the building have to meet the applicable energy requirements). Historical buildings that have no official heritage status, do have to meet all the energy requirements. This includes buildings that are situated in the zone of cultural, historical and/or esthetical value (CHE-zone) or that are included on the scientific inventory. These buildings are also part of historic districts and the HeriTACE project explicitly aims to also search for solutions for optimal and balanced renovation in those buildings.

Therefore, in the renovation baseline scenarios for those elements that are of high value, there are scenarios that meet the energy requirements, and also some that are applicable in situations where only limited impact measures are allowed and energy performance of the element might not be reached.

3.5.1. Use scenarios

Building use: function

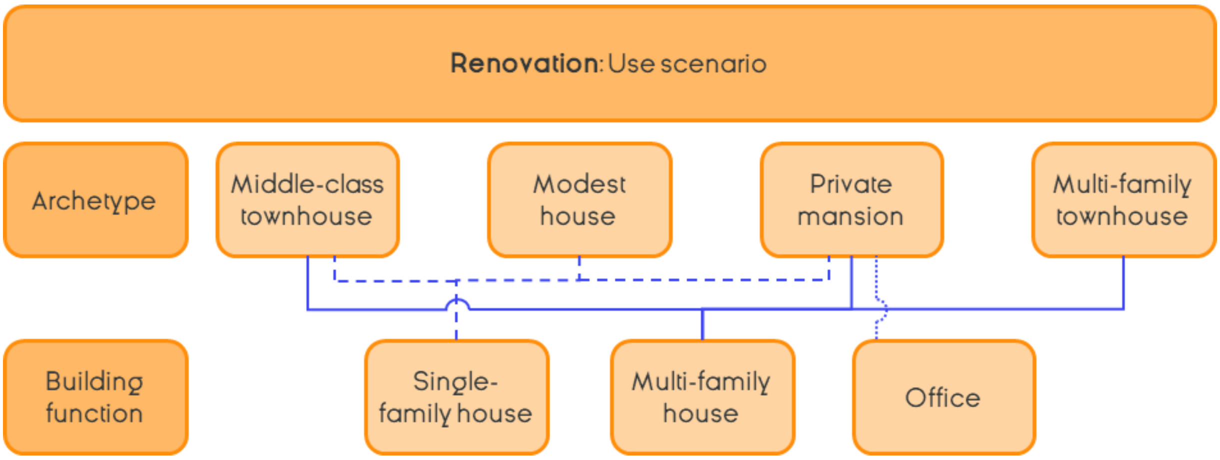


Figure 15: Renovation Use scenarios (BE)

Following renovation, the use of the townhouses is subject to change. The middle-class townhouse, originally designed as a single-family dwelling, may be converted into a multi-family residence comprising several apartments within the same building. In cases where it remains a single-family home, the attic is included within the heated volume, while the basement is excluded. In multi-family configurations, both the attic and basement are brought into use. The modest house continues to function as a single-family dwelling after renovation, due to its relatively limited size. The original rear extension is replaced with a larger, contemporary addition on the ground floor.

The private mansion may continue to be used as a single-family residence post-renovation, with the attic incorporated into the heated volume. However, given its substantial size, conversion to a multi-family dwelling or office space is also feasible, in which cases both the attic and basement are utilised. The multi-family townhouse remains a multi-family residence, but here too, the attic and basement are brought into active use.

Comfort – temperature settings (heating and cooling)

The temperature settings for heating (no cooling is present) are the same as for the pre-renovation baseline.

3.5.2. Building envelope scenarios

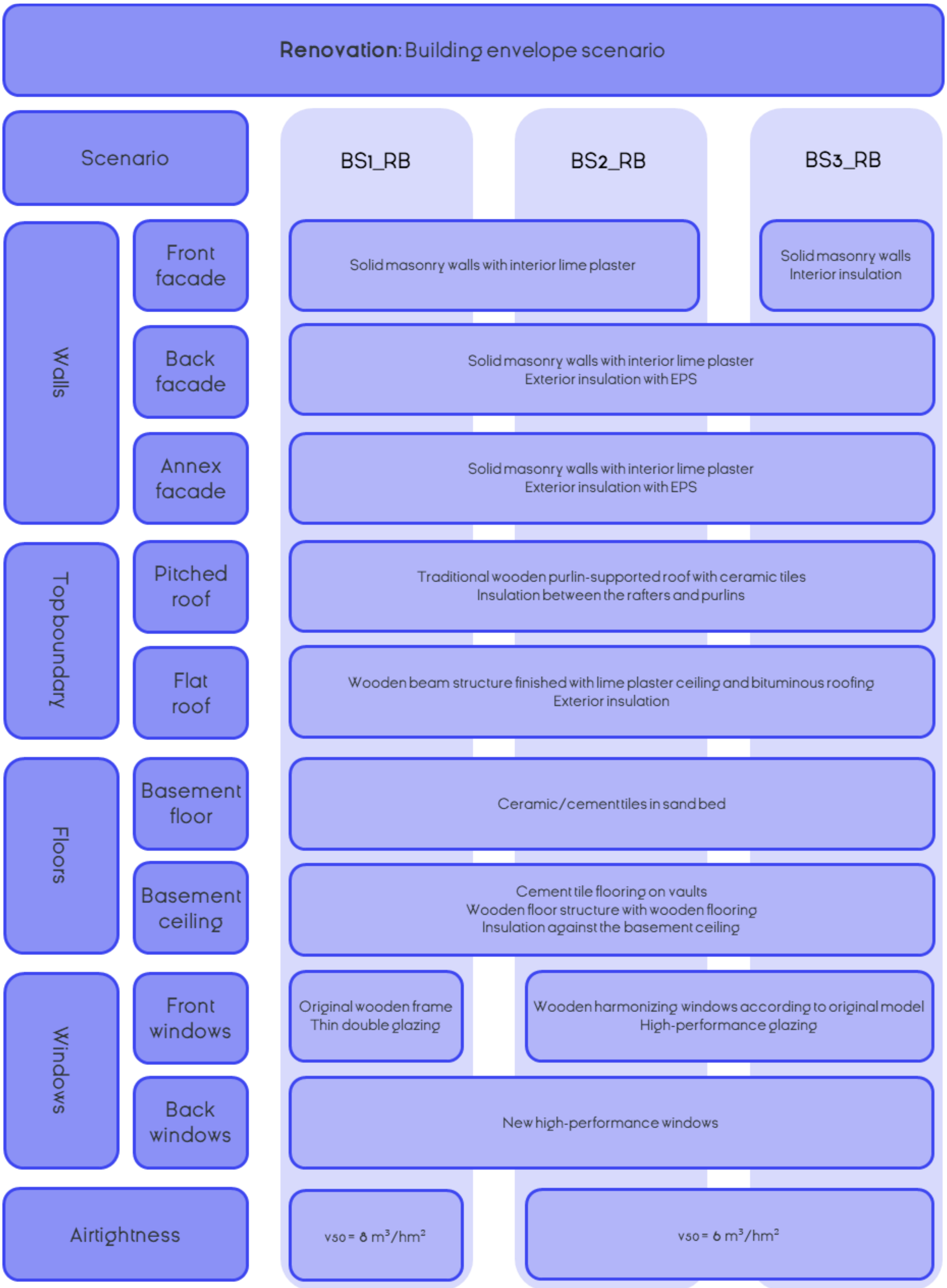


Figure 16: Renovation building envelope scenarios (BE)

As in the pre-renovation building envelope scenarios, the retrofit approach is not really influenced by the archetype, but more by the heritage value and the pre-renovation condition of the building element. In general, the less valuable elements that are not exempt from energy regulations are insulated according to current standards. Other elements, that are more valuable need a more tailored approach, that is described in the three different renovation baseline building envelope scenarios. As this concerns energy renovation, the structure of the building remain untouched. The (less valuable) **walls** of the back façade and the annex are treated similarly in all scenarios: they are upgraded with an ETICS insulation system that meets current high insulation standards, using EPS and finished with cement plaster. In all three scenarios, pitched **roofs** are insulated internally between rafters and purlins, while flat roofs receive external insulation, all meeting current high insulation standards. The basement **floor** remains unchanged, but its ceiling is insulated—both against the vaulted ceilings and in between the wooden flooring. Finally, all the **windows** of the back façade and annex are replaced with new ones featuring high-performance frames and glazing.

BS1_RB: Insulated building with thin double front window glazing, without front façade insulation

This scenario is applicable to buildings that are classified under HV_I, buildings with a highly valuable façade, windows and interior. This corresponds with the pre-renovation scenario BS1_PB, where all the windows were the original windows. Due to heritage constraints, the front façade retains its original solid masonry construction and remains uninsulated (in contrast to the rear and annex facades).. Owing to the heritage value of the front façade windows, these are preserved, with the existing glazing replaced by thin double glazing that is installed within the original wooden frames. Assuming that the original windows in the front façade still remain leaky, but the rest of the building is renovated with today's conventional attention for airtightness, the average envelope v50-value is assumed 8 m^3/hm^2, which is higher than for the other scenarios.

BS2_RB: Insulated building with high performance (harmonized) front windows, without front façade insulation

This scenario is applicable to the heritage value scenario HV_II., HV_III.1 and HV_III.2., where the pre-renovation scenario consisted of contemporary windows in the back façade and original windows in the front façade for BS2_PB and contemporary windows in the front façade for BS3_PB. Todays practice is replacing the windows in the front façade with modern high-performance windows, that are made according to the original model (harmonized windows). These windows need to harmonise with the original materials and surrounding context but allow the use of high-performance glazing and frames. As all the other windows are assumed to be replaced with standard new windows with high performance glazing, this scenario assumes a whole building renovation where conventional airtightness measurements are taken. Consequently, the airtightness is improved relative to BS1_RB, with average envelope v50-value of 6m^3/hm^2.

BS3_RB: Insulated building with high performance (harmonized) front windows, with interior front façade insulation

This scenario is applicable for buildings with an interior that is not valuable (HV_III.3). The pre-renovation condition of these buildings is the presence of original windows in the front façade. This scenario mirrors BS2_RB in all respects except for the front façade, where interior insulation is applied on each level to improve the thermal performance without altering the external appearance. Contemporary windows with harmonising design and materials are installed in the front façade, while new high-performance windows are used at the rear. Airtightness is comparable BS2_RB, with an average envelope v50-value of $6m^3/hm^2$.

3.5.3. Space conditioning scenarios

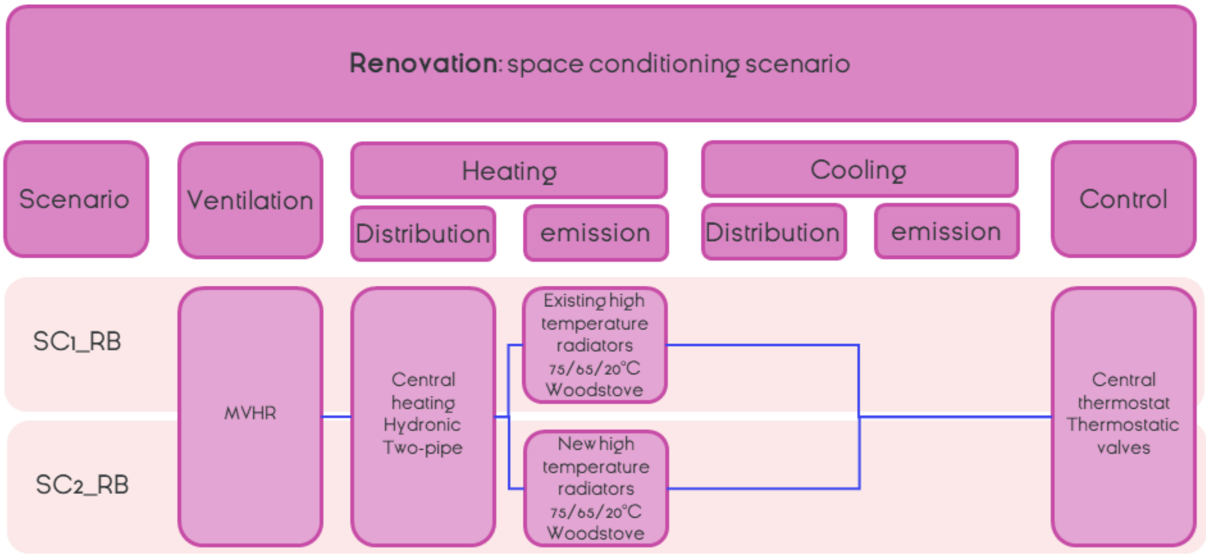


Figure 17: Renovation space conditioning scenarios (BE)

Since the renovation baseline builds on the pre-renovation baseline for space conditioning, it is similar across all archetypes. However, in cases where changes in building function are observed post-renovation, a distinct scenario is introduced to address these modifications. A central hydronic heating system is retained, and existing high-temperature radiators are preserved where feasible (SC1_RB). In newly heated spaces, additional high-temperature radiators are installed, designed for a 75/65/20°C regime (SC2_RB). The heating system remains controlled by a central thermostat located in the living room, while thermostatic radiator valves allow for localized temperature regulation. Although no mechanical cooling system is introduced, a central mechanical ventilation system with heat recovery (MVHR) is implemented in compliance with national standards (NBN D50-001).

3.5.4. Energy scenarios

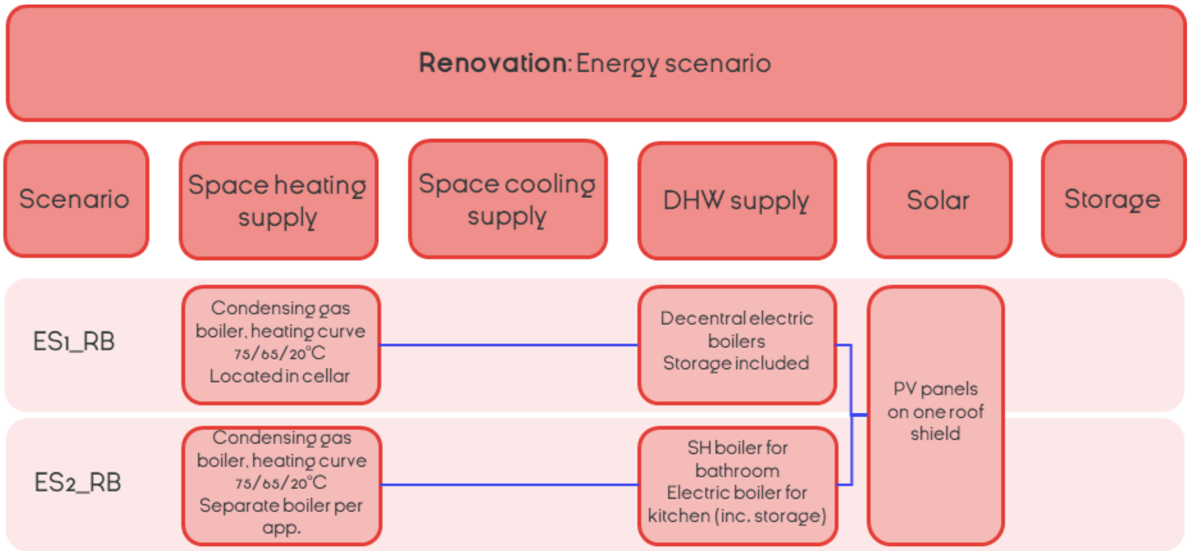


Figure 18: Renovation Energy scenarios (BE)

ES1_PB: Gas boiler, electric DHW boilers

The first energy scenario applies to archetypes that may retain single-family (or office) use after renovation – specifically, the middle-class townhouse, the modest house, and the private mansion. The renovation baseline heating supply system remains largely consistent with the pre-renovation baseline, with the notable upgrade to a high-efficiency contemporary condensing gas boiler operating at a reduced supply temperature of 75 °C for space heating. DHW continues to be provided locally via decentralized electric boilers installed near the tap points. In addition, a limited installation of photovoltaic (PV) panels is assumed, positioned on the most solar-exposed roof surface.

ES2_PB: Gas boiler per app., electric DHW boilers

The second energy scenario is relevant for archetypes that accommodate multi-family use after renovation, such as the middle-class townhouse, private mansion, and multi-family townhouse. In this case, each apartment is equipped with an individual condensing gas boiler for space heating, also supplying DHW to the bathroom. Kitchen DHW is provided by a separate electric boiler with integrated storage. As in the first scenario, a limited number of PV panels is assumed on the most favorable roof area for solar exposure.

4. Norway: baseline scenarios

4.1. Overview

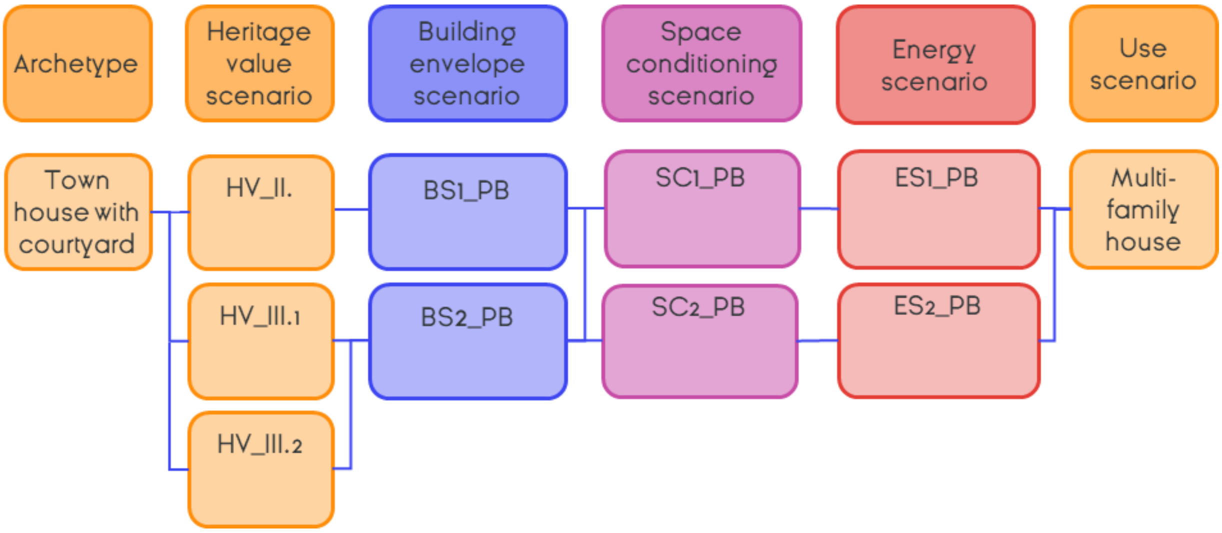


Figure 19: Overview of the pre-renovation baseline scenarios (NO)

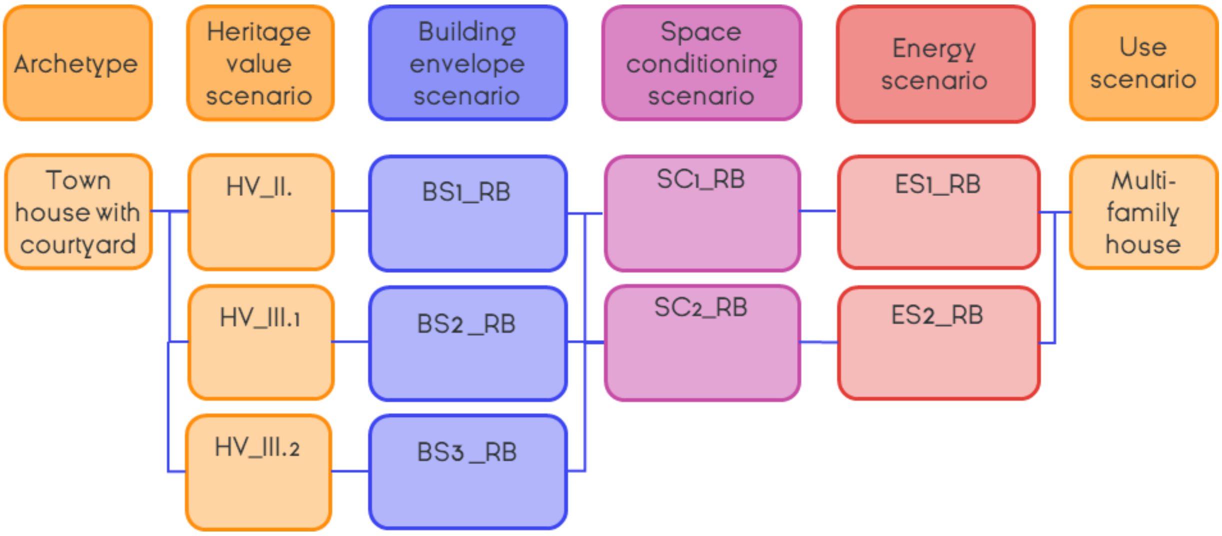


Figure 20: Overview of the renovation baseline scenarios (NO)

4.2. Archetype

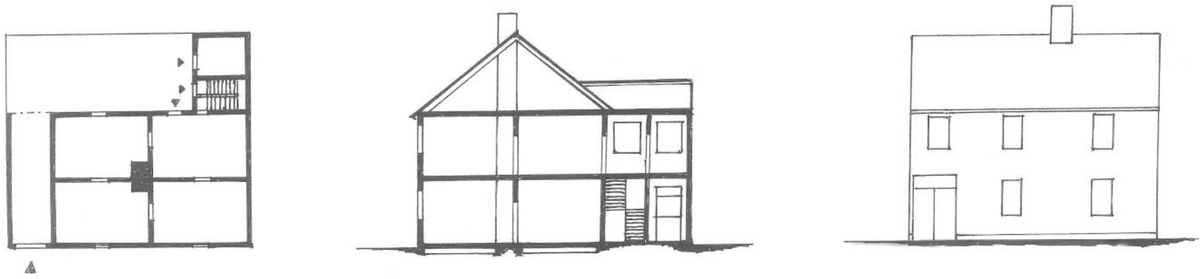


Figure 21: Overview of the Norwegian townhouse with courtyard archetype by plan, section, and facade (NO)

The chosen archetype is the townhouse with courtyard, with a timber/wood log construction. Traditional log buildings in Norway hold significant cultural value. Adapting these structures for modern comfort without compromising their heritage value, is challenging. Introducing new materials for insulation must be done carefully to avoid damaging the buildings.

The primary structure is made of massive wood, featuring either a wood log system or a system composed by vertical wooden planks within a timber frame. The prevailing construction is wood log system in the front buildings (towards the street), and either wood log or timber frame in the outbuildings (wing- and back yard buildings). More details of these two construction systems are described in the following chapters.

Main features of the archetype include:

- Often four-room plan with courtyard, often with outbuildings;
- Mainly residential, some commercial activities on the main floor;
- One to two (sometimes three) floors; attic under the roof;
- Normally saddle/gable roof;
- Location: directly passage from the street, often with a small backyard and/or outhouse(s);
- Dense housing, the townhouses are positioned very close, shoulder-by-shoulder.

4.3. Heritage value scenarios

Figure 22 shows heritage value scenario's ranking from scenario HV_0 with the highest value to HV_IV without heritage value. The HeriTACE project's Norwegian archetype focuses on the HV_II, HV_III.1, and HV_III.2 scenarios, as the most representative and replicable for the heritage townhouse archetypes. For each scenario, the building sections indicate the heritage value categories that apply to each building component.

Several of the buildings in Bakklandet have high individual heritage value. For all the historic buildings with timber log and timber frame constructions, the construction itself has high heritage value and should not be intervened. In addition to this, the whole heritage building environment is also part of a protected neighbourhood. The entire area is governed by a heritage protection plan, in addition to being protected as a cultural heritage area under a special zoning designation in the municipal spatial plan. The buildings thus possess high heritage value not only individually, but also as integral elements of a larger urban fabric. As such, aspects like structure, form, scale in relation to the street, and spatial relationships with adjacent buildings are also protected, thereby constraining the scope for modifications also for newer building. These considerations are important both for existing buildings with varying degrees of heritage value and for newer constructions that have replaced earlier structures.

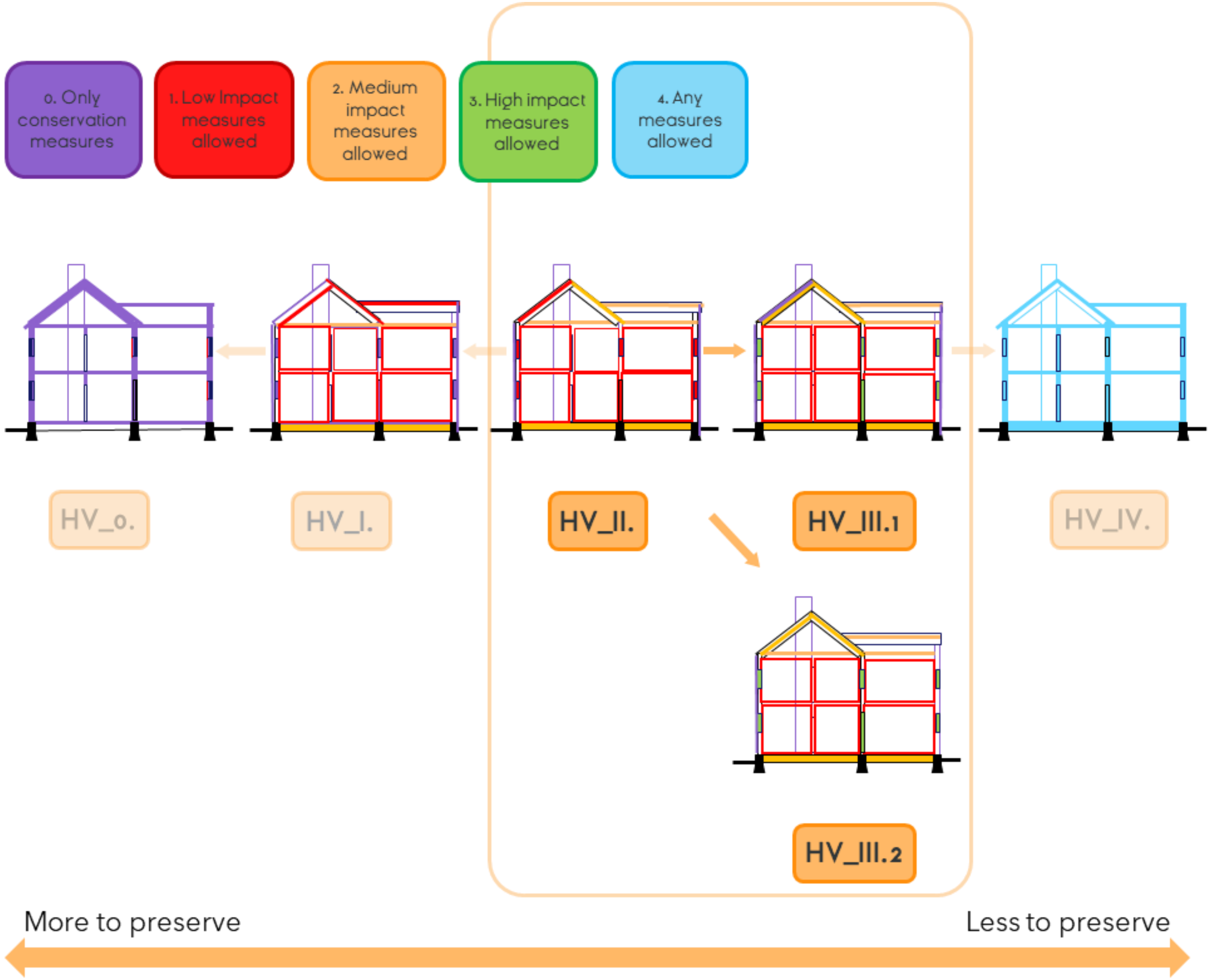


Figure 22: Overview of heritage value scenarios (NO)

HV_0. Highly valuable building as a whole

The building as a whole has significant heritage value, and few alterations have been made throughout its history. Therefore, the building envelope and interior must be entirely preserved, and only limited interventions are allowed (Category 0 and Category 1 apply to most elements). For example: According to the city antiquarian, any change is subjected to building permits, is to be considered at an individual level, and will most likely be refused.

This heritage scenario primarily applies to listed buildings, which are legally protected by a ministerial decree, in accordance with the Cultural Heritage Act. There are not many individually listed buildings in the neighbourhood, and they would require a more case-specific approach, therefore this heritage condition will not constitute the central focus of the HeriTACE project.

HV _I. Highly valuable facade, windows and interior

In this highly valuable scenario, the building is labelled as of level A on the municipal cultural heritage map, however not listed.

The main construction and facades with original cladding, including the windows (at least towards the street), are of high value. The back façade might also have high heritage value, and all, or at least certain windows, should be retained. A valuable interior and/or some valuable interior elements are present and are to be preserved. The interior is usually not listed, opening for low impact and reversible non-extensive interventions. The original windows and doors are listed as part of the façades so only conservation measures are allowed. If, however, windows are not original, they might be replaced with high-quality replica and higher energy performance, while at the same time preserving and maintaining as much as possible of the authentic surrounding materials, mouldings, etc.

This heritage value scenario is not applicable for the assessed case-study buildings in the Norwegian case but is present in the neighbourhood.

HV_II. Highly valuable façade with typical valuable interior elements

The building is of high antiquarian value (mainly level B on the municipal cultural heritage map), however not listed.

This heritage value scenario has a highly valuable façade towards the street (with original cladding), which is not to be intervened. The windows are not original, but with heritage value, and can undergo small interventions. They have old, wooden frames with single glazing, and single interior casement windows (introducing thin double glazing, replacement of single glazing with diluted double glazing, installation of gaskets, etc.).

The back façade, including the windows, has high heritage value. For buildings in this category, the visible roofing can be changed if the facade and the proportions are not changed. The original roofing can be reinstated, or the roof can be resurfaced to original model. Some interior elements are valuable. The walls, floors and ceilings including valuable elements are thus to be preserved, but small interventions are possible.

One of the buildings included in the assessed built heritage inventory is classified under this heritage value scenario.

HV_III.1 Highly valuable facade with low valuable windows

The building is of high antiquarian to antiquarian value (Level B to C on the municipal cultural heritage map), however not listed.

This heritage value scenario, together with HV_III.2, is the most prevalent situation in the neighbourhood, with a highly valuable façade towards the street (not to be intervened). The back façade has high heritage value. The visible roofing is valuable. The original roofing material, where this has been changed, should be restored if possible. As interventions towards the back yard have less impacts to the visual coherence of the neighbourhood´s aesthetic consistency and overall appearance, they tend to be more often approved.

The windows can, be completely removed and remodelled, since they are not original. New, energy efficient windows should be produced according to the original, with historically correct appearances. Some interior elements are valuable. The walls, floors and ceilings including valuable elements are thus to be preserved. However, the interior is usually not listed, opening for low impact and reversible, and non-extensive interventions.

One of the buildings included in the assessed built heritage inventory can be classified under this heritage value scenario.

HV_III.2 Valuable front facade with low valuable windows

Buildings in this scenario are of high antiquarian to antiquarian value (Level B to C on the municipal cultural heritage map), however not listed.

Together with HV_III.1, this is the most prevalent building scenario in the neighbourhood, with a valuable façade towards the street. The back façade has some heritage value. Due to earlier replaced cladding and windows, the buildings under this category have façades with lower heritage value and more extensive interventions can be performed.

The windows can be completely removed and remodelled, since they are not original. New, energy efficient windows should be produced according to the original, with historically correct appearances. Some interior elements are valuable. The walls, floors and ceilings including valuable elements are thus to be preserved. However, the interior is not listed, opening for low impact and reversible, non-extensive interventions.

One of the buildings included in the assessed built heritage inventory can be classified under this heritage value scenario.

HV_IV. Townhouse without heritage value

This is a scenario for a building without any individual heritage value, representing a more recent terraced townhouse with the same typological structure. While newer buildings can be upgraded for energy efficiency without the need to account for individual heritage elements, modifications to heritage features—such as structure, form, and proportions—can influence the overall character of the neighbourhood and must therefore be carefully governed and preserved.

None of the buildings included in the assessed built heritage inventory can be classified under this heritage value scenario but is present in the neighbourhood.

4.4. Pre-renovation baseline scenarios

4.4.1. Use scenarios

Building use: function

Bakklandet has experienced a profound transformation in its urban function and character since the first buildings were established in the mid-17th century, when the area developed as Trondheim's first suburb. Initially established as a working-class district, as Trondheim was home to seafarers, craftsmen, and labourers, and was defined by its modest wooden architecture and proximity to the city's industrial and commercial activities. During the mid-20th century, the area faced significant decline and was threatened by urban redevelopment plans. Strong civic opposition led to the abandonment of these plans in the early 1980s. This marked the beginning of a period of revitalisation, during which Bakklandet's historic buildings were restored and repurposed. From the 1980s and 1990s onwards, the area gradually evolved into a mixed-use neighbourhood, characterised by a blend of residential housing and small-scale commercial enterprises such as cafés, boutiques, and restaurants. Today, Bakklandet is recognised as a culturally vibrant and architecturally preserved district, balancing its historical heritage with contemporary urban life.

Most of the buildings were originally designed as single-family dwellings, with outbuildings in the backyard for stables, storage, and craftsmen activities/workshops. Later, they have been remodelled into multi-family buildings. In some buildings, cafés, pubs, and/or restaurants have been established on the ground floor, thus some buildings only have a residential use, and some have a mixed residential and commercial use.

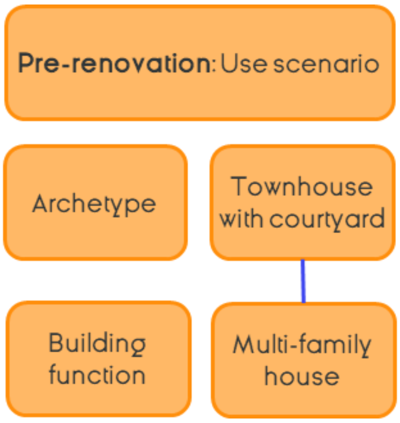


Figure 23: Pre-renovation scenario (NO)

In the pre-renovation baseline, the archetype Townhouse with courtyard is mainly used as a multi-family dwelling. In addition, some of the buildings have a café, shop, restaurant, or workshop on the ground floor, or also in the back yard buildings/outhouses. In general, there are no basements. In some of the buildings, the attic has been upgraded for use, then mainly as bedrooms. The attics are partly not in active use and serve primarily as storage or technical spaces or have been renovated and serve as bedrooms. The attics' original function was to serve as a cold buffer towards the colder ceiling/roof, in addition to serving as a storage loft, and was not common for use. For the baseline pre-renovation scenario, it is assumed that the attic is not conditioned (so use as a storage area).

Comfort and temperature settings (heating and cooling)

The (electric) radiators in the living room, kitchen, and hallways are regulated as outlined in Table 1 In the bedroom, heating remains off at all times. The window is assumed to be minimally open throughout the night, except when outdoor temperatures drop below approximately -5 °C, and the bedroom door remains closed.

Table 1: Overview of the design guidelines according to Norwegian practices

Room	Day Setpoint	Night Setback	Notes *(CEN, 2019; SINTEF Byggforsk., 2017)*
Living room	21°C	17°C	Central thermostat location; main heated zone
Bedrooms	16°C	8°C	Lower comfort expectation, especially at night. There is commonly no heater and window opening during the night. It is common to keep the door closed
Kitchen	19°C	16°C	Often heated via adjacent rooms
Hallways	16°C	14°C	Typically, unheated, or indirectly heated
Bathroom	24°C (in use)	18°C	Heated only during use; electric floor heating common

4.4.2. Building envelope scenarios

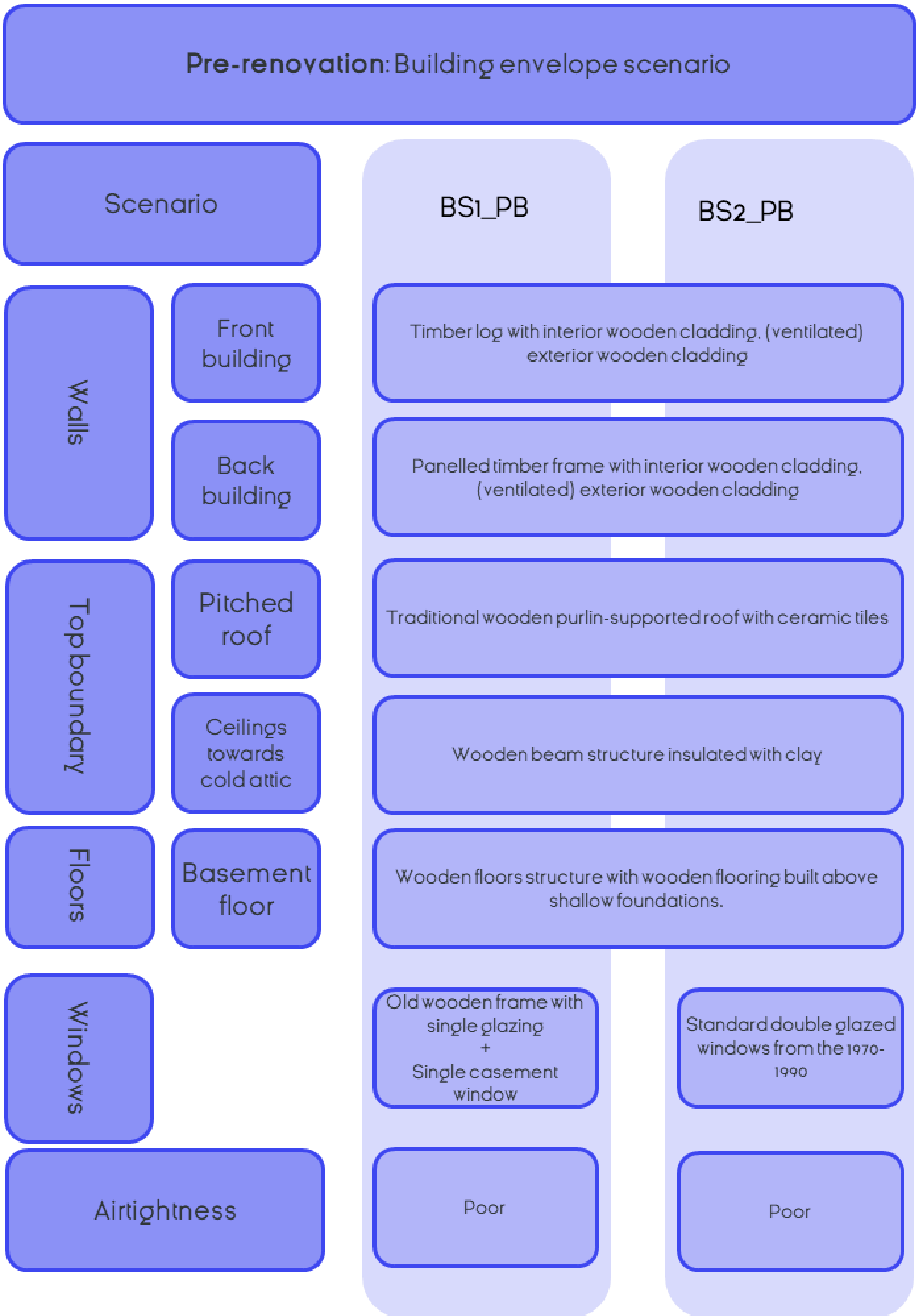


Figure 24: Pre-renovation building envelope scenarios (NO)

There are two different building envelope scenarios for the pre-renovation baseline. For walls, roofs and floors they are the same, but the situation for the kind of windows is different.

The prevailing construction is a solid timber log structure in the front buildings, and a panelled timber-framing in the back yard buildings. There is clay infill in the wooden ceiling- and basement floors so they remain original. Apart from the original materials, no later insulation layers have been added.

BS1_PB: Old windows

In this scenario, the old wooden window frame with old or original single glazing exists. Due to the Norwegian climatic condition an interior single casement is also added in newer times. These windows must be preserved.

BS2_PB: Double glazed windows

In this scenario, all windows have already been replaced with double-glazed windows between 1970 and 1990.

4.4.3. Space conditioning scenarios

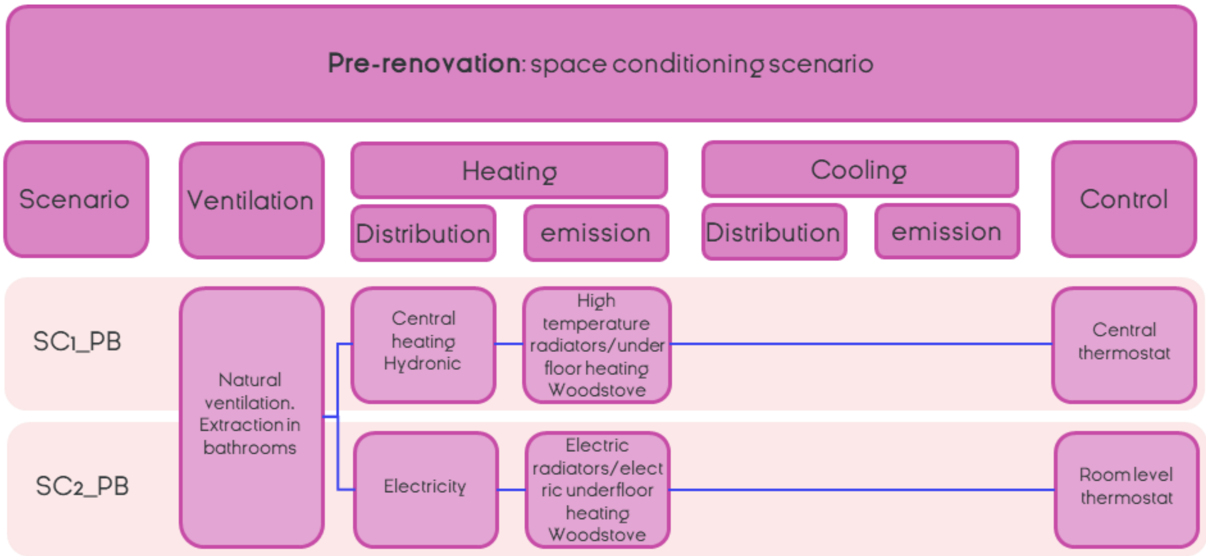


Figure 25: Pre-renovation space conditioning scenarios (NO)

The pre-renovation baseline for Bakklandet buildings reflects typical Norwegian practices from the late 19th and late 20th centuries. A central hydronic heating system, supplied by an electric boiler replaces the original oil- or wood-fired systems. It distributes hot water to high-temperature radiators (90/70/20°C) in main rooms, and underfloor heating in the bathroom is possible. The second scenario uses directly electric radiators (with sometimes electric underfloor heating in the bathroom. Bot scenarios assume woodstoves in the living rooms to provide extra comfort. Heating is controlled by a central thermostat in the living room with basic on/off logic for the central heating system. Electric radiators, where present, have manual or thermostatic controls on a room level. No mechanical cooling or central ventilation is present. Ventilation relies on window airing and natural infiltration, with local exhaust fans in kitchens (when cooking) and bathrooms.

4.4.4. Energy scenarios

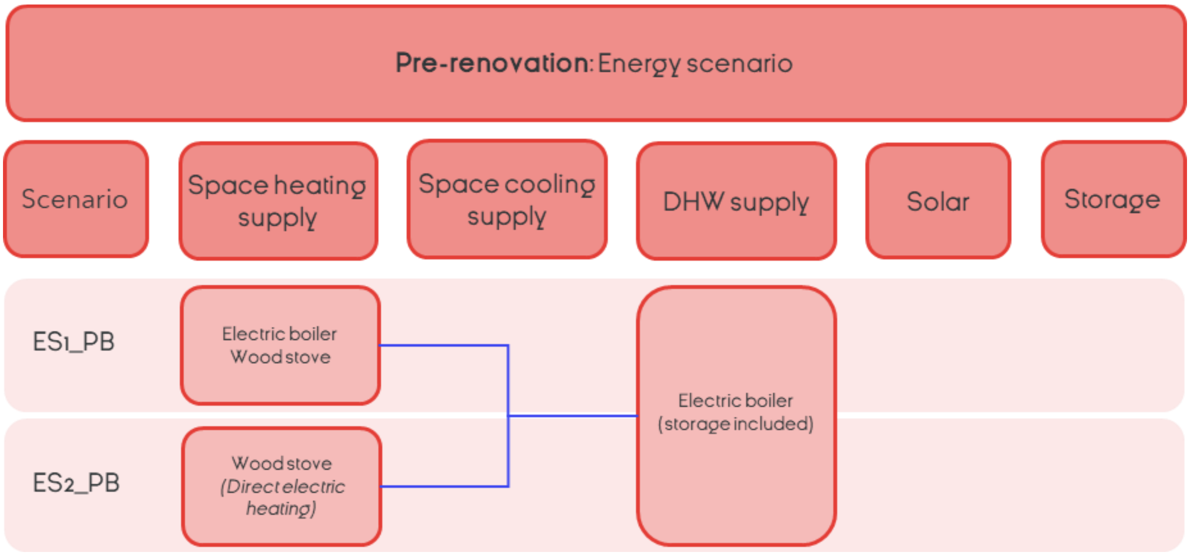


Figure 26: Pre-renovation energy scenario (NO)

Both energy scenarios include an electric boiler for the production of domestic hot water. Additionally, wood-burning stoves are assumed in both scenarios, as they provide extra heating in winter. For both scenarios, no cooling, solar or storage systems are assumed. The only difference is the way space heating is provided (apart from the wood stoves). In ES1_PB, a central hydronic heating system is supplied by an electric boiler. In ES2_PB, direct electric heating assures adequate heating.

ES1_PB: Electric boiler, wood-burning stove

For the first pre-renovation energy scenario, space heating is provided by an electric boiler. This electric boiler provides the necessary hot water for the central hydronic heating system. Wood-burning stoves are typically present in living rooms, to provide additional heating in winter. Domestic hot water is heated using electric boilers that include storage tanks. No solar systems or additional energy storages are present.

ES2_PB: Electric direct heating, wood-burning stove

For the second pre-renovation energy scenario each room has an individual electric heater (or electric underfloor heating). Apartments also have wood-burning stoves that are used for heating during winter when electricity prices are high. Domestic hot water is heated using electric boilers that include tanks. No solar systems or additional energy storages are present.

4.5. Renovation baseline scenarios

4.5.1. Use scenarios

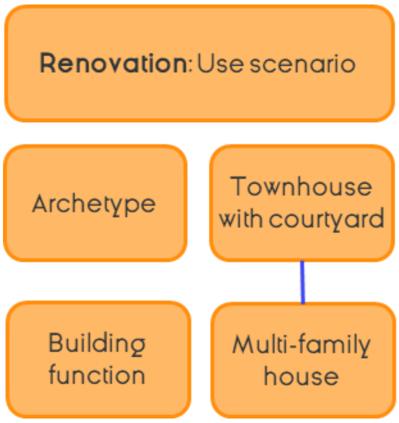


Figure 27: Renovation use scenario (NO)

The renovation use scenario is identical to the pre-renovation use scenario. In the renovation use scenario, the archetype Townhouse with courtyard is mainly used as multi-family dwellings. In the continuance, some of the buildings will have a café, restaurant, or workshop on the ground floor, or also in the back yard buildings/outhouses. Some attics might be transformed from cold space to living space. The authorities' willingness to allow new roof windows is not known, but such interventions have already been allowed to a certain extent.

4.5.2. Building envelope scenarios

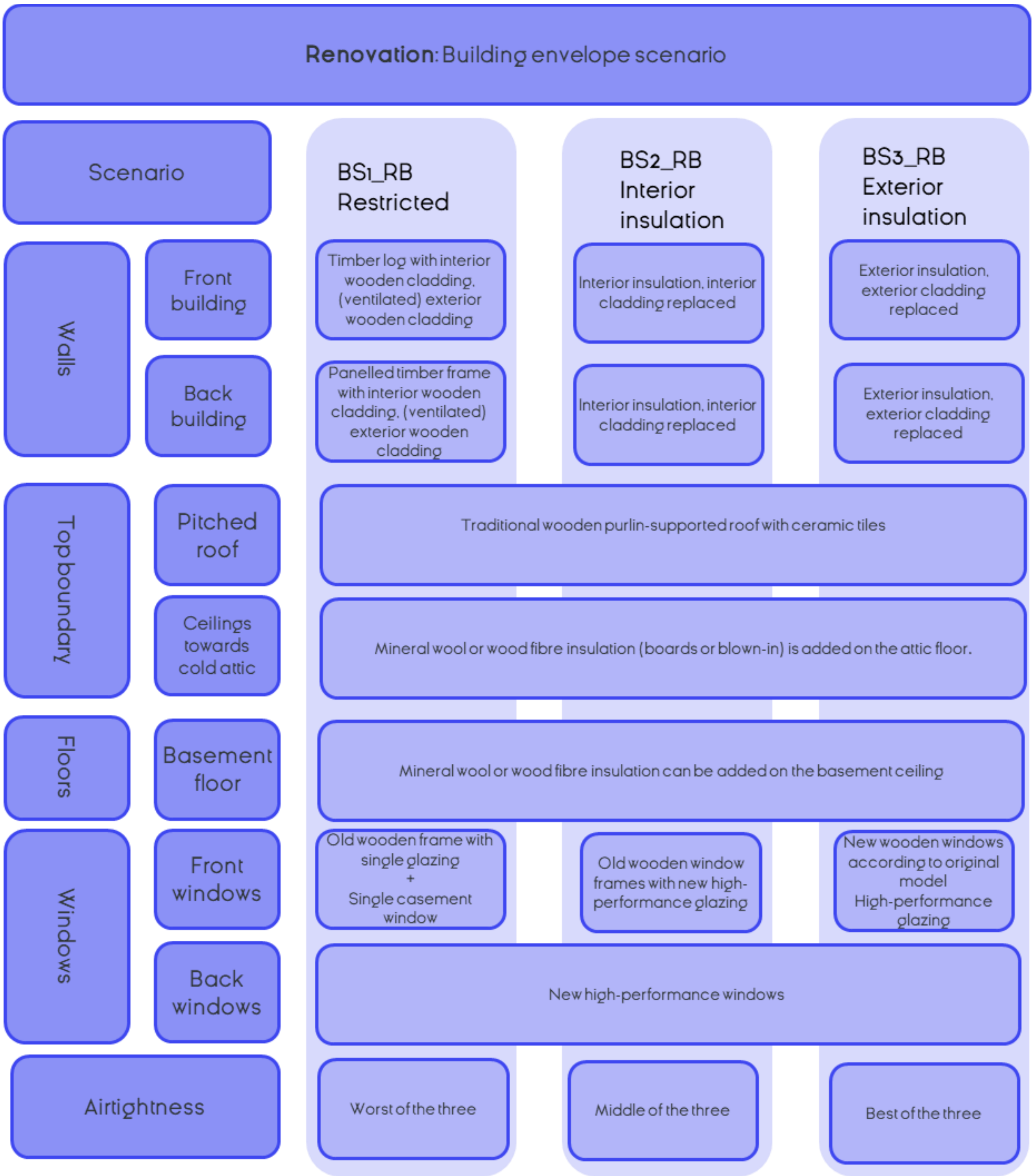


Figure 28: Building envelope renovation scenarios (NO)

BS1_RB Restricted

In this scenario, the prevailing construction is a solid timber log structure in the front buildings, and a paneled timber-framing in the back yard buildings, and the walls remain uninsulated. The clay infill in the ceiling- and basement floors is removed, and modern insulation material (typical mineral wool) is added. Removal of the stub loft clay and subfloor materials is permitted, on the condition that the intervention does not compromise any interior elements of heritage value. The existing windows in the front building must be preserved, with the interior single casement added. The restrictions are not evident for the back buildings and new high-performance windows can be applied.

BS2_RB Interior insulation

In this scenario, the solid timber log structure and paneled timber-framing can be insulated from the inside/interior side, while not touching the valuable and original wooden cladding. The interior cladding is most often removed during this process. The stub clay in the ceiling floor and the basement floor is removed, and modern insulation material (typical mineral wool) is added. The old window frames shall remain, but new high-performance glazing is permitted. If the windows are newer, but with poor performance, modern, new wooden windows according to original model, with high-performance glazing can be used.

BS3_RB Exterior insulation

In this scenario, the solid timber log structure in the front buildings and the paneled timber-framing in the back yard buildings can be insulated from the out-/exterior side. The exterior cladding (which in this case is not original) is removed, barrier layers and insulation is added in addition to a new cladding. The clay in the ceiling floor and the basement floor is removed and modern insulation material (typical mineral wool) is added. Modern, new wooden windows, according to original model with high-performance glazing, are introduced.

4.5.3. Space conditioning scenarios

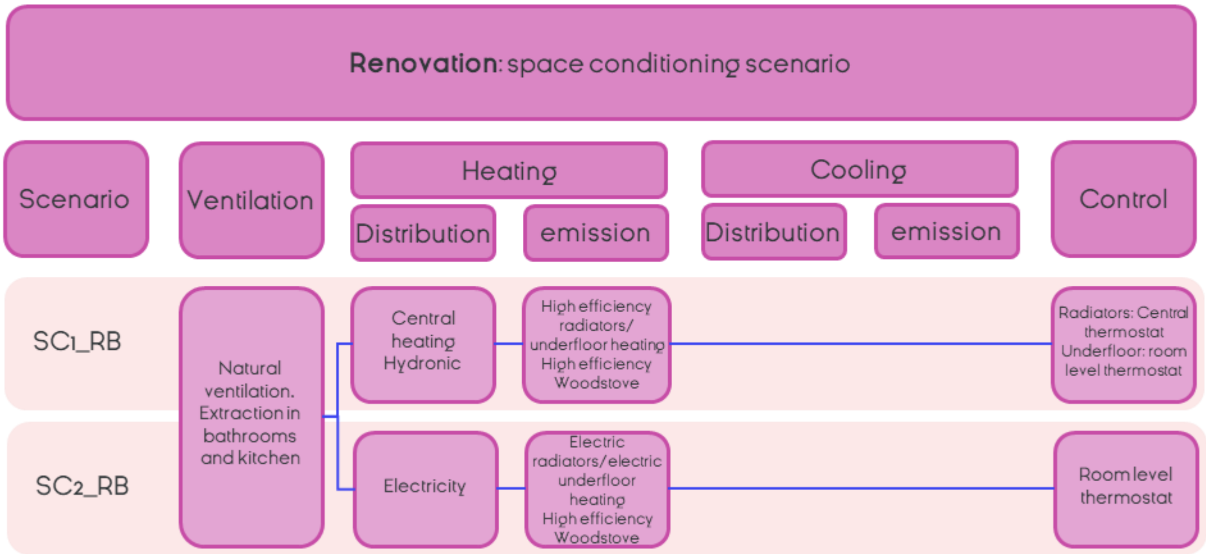


Figure 29: Space conditioning renovation scenario (NO)

The renovation baseline for Bakklandet buildings prioritizes preservation and selective improvements over full compliance with new construction standards. The selected renovation approaches involve either replacing the original cast iron radiators with more efficient radiators or with electric heaters. Consistent with pre-renovation practices, bedrooms were frequently left without a heating source, while living rooms typically combined wood stoves with either the electric heater or the new radiator. Older coal-burning or inefficient wood stoves and open fireplaces are replaced by modern, high-efficiency wood stoves that emit fewer particulate emissions and offer improved combustion performance. Electric heaters are commonly installed in kitchens and hallways, while bathrooms are usually equipped with electric underfloor heating.

When preserving the hydronic central heating, the radiators are still controlled by a central thermostat, while both electric radiators and underfloor systems are generally controlled by room-level thermostats. These may be manually adjustable or programmable with time-based schedules, although they are most often left at fixed settings. Ventilation continues to rely on window airing and natural infiltration, with local exhaust fans installed in kitchens and bathrooms for moisture control.

4.5.4. Energy scenarios

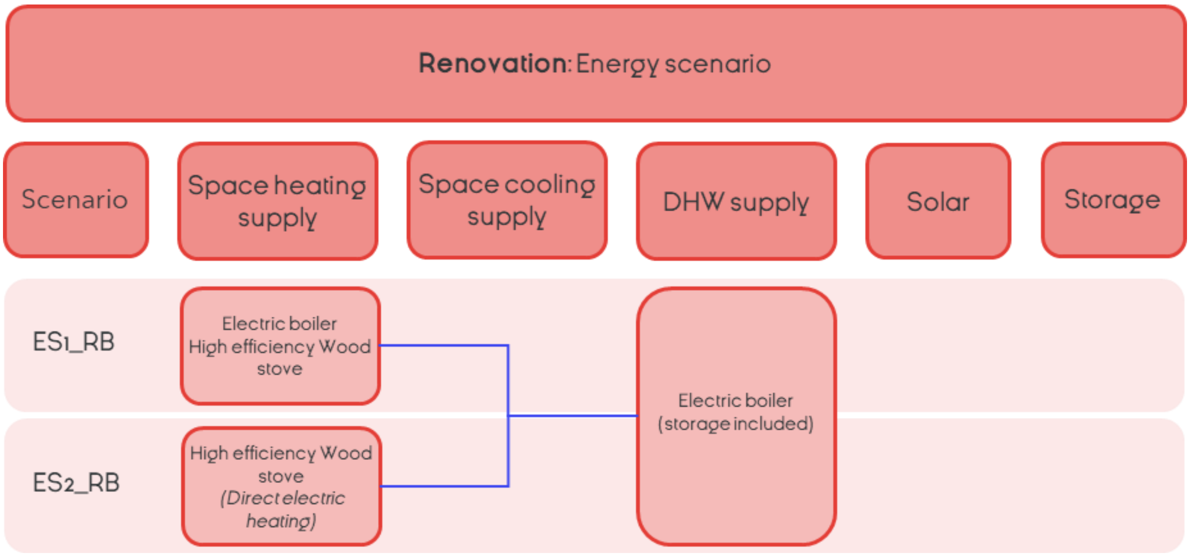


Figure 30: Renovation energy scenario (NO)

Both renovation baseline energy scenarios include an electric boiler for the production of domestic hot water. The old and inefficient wood stoves are replaced by new, more efficient ones in both scenarios. Additionally, no cooling, solar or storage systems are assumed. The only difference is the way space heating is provided (apart from the wood stoves). In ES1_RB, a central hydronic heating system is supplied by an electric boiler. In ES2_RB, direct electric heating assures adequate heating.

ES1_RB: Electric boiler, wood-burning stove

Space heating is again provided by an electric boiler, that produces the necessary hot water for the central hydronic heating system. Wood-burning stoves are still assumed in living rooms, but older coal-burning or inefficient wood stoves and open fireplaces are replaced by modern, high-efficiency models. Domestic hot water is heated using electric boilers that include storage tanks. No solar systems or additional energy storages are present in the renovation baseline.

ES2_RB: Electric direct heating, high efficiency wood-burning stove

Direct electric heating is providing the space heating (through electric heaters and underfloor systems). Wood-burning stoves are still assumed in living rooms, but Older coal-burning or inefficient wood stoves and open fireplaces are replaced by modern, high-efficiency models Domestic hot water is heated using electric boilers that include tanks. No solar systems or additional energy storages are present.

5. Estonia: baseline scenarios

5.1. Overview

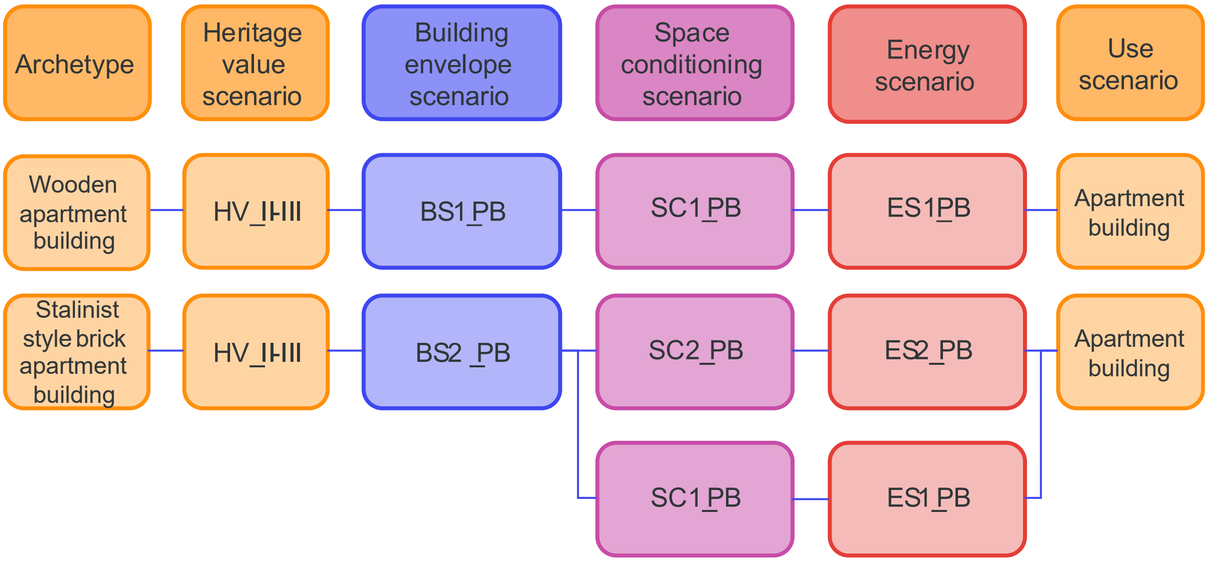


Figure 31: Overview of the pre-renovation baseline scenarios (EE)

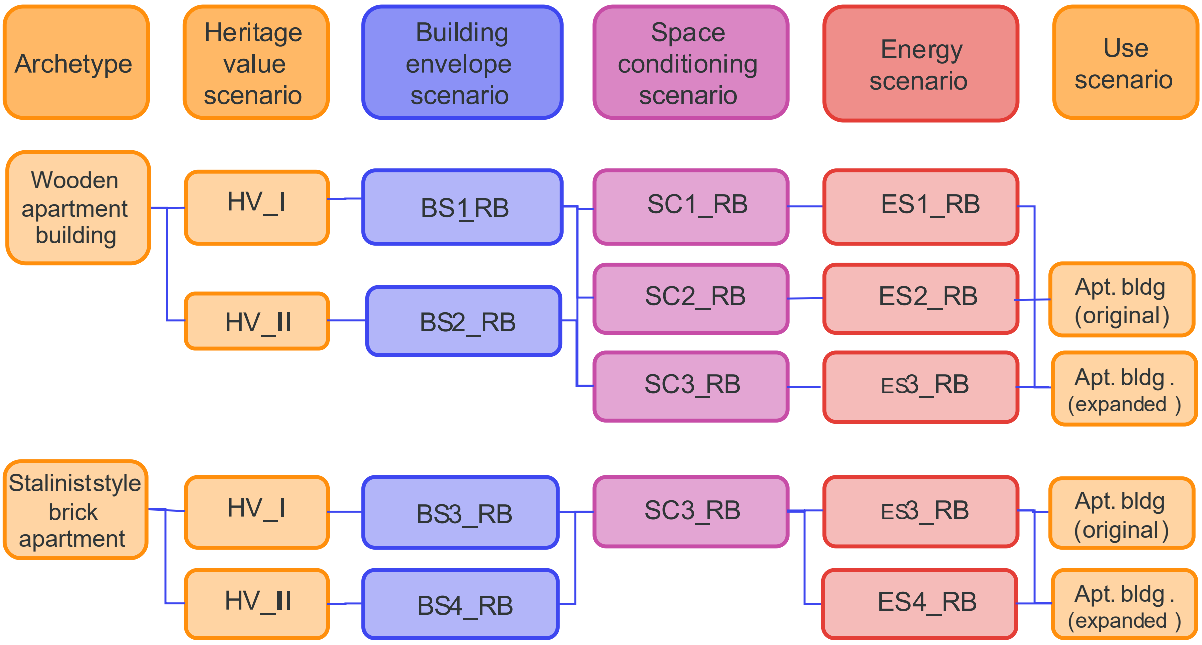
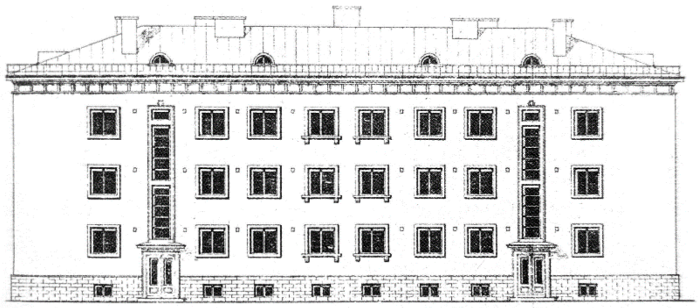


Figure 32: Overview of the renovation baseline scenarios (EE)

5.2. Archetypes

Wooden apartment building ('Lender' type)



'Stalinist' style brick apartment building

Figure 33: Overview of townhouse archetypes by facade (EE)

One of the most typical **wooden apartment buildings** in Tallinn is referred to as the 'Lender's' building type. The type originates from the end of the 19th and beginning of the 20th century and was designed for poor Estonian nationality peasants who came from the countryside to work in various industrial sites and could only afford to rent an inexpensive apartment. The Lender's buildings typically have two floors, are symmetrical and made of limestone (foundation and plinth) and horizontal logs. The facade is covered with horizontal boarding, some are more decorative and others very simple, the front door being the only aesthetically designed element. The roof type is open gable.

The 'Tallinn' building style **wooden apartment buildings** were constructed in 1920-1930s and are characterized by one central stairwell made of brick. This building type was designed to be rented mainly to upper working-class and middle-class families but there are also some with very large, bourgeois apartments. Those buildings are constructed of limestone (foundation and plinth), planks or wooden truss and bricks (stairwell). The facade can be covered in wooden boarding or with plaster. The roof type can be hip, jerkinhead, gambrel or mansard. The Tallinn buildings have mostly two floors but for a short period also adding a third floor was allowed.

Stalinist style apartment buildings constructed in 1940-1955 represent a variety of buildings both small and large, wooden and brick. In this project, Stalinist style buildings made of brick were selected. In Estonia, this type of apartment buildings were built in place of those destroyed in WWII and constructed mainly to accommodate workers who immigrated from Soviet Russia. Behind the highly decorated facades were often apartments with simple living conditions and little decoration.

5.3. Heritage value scenarios

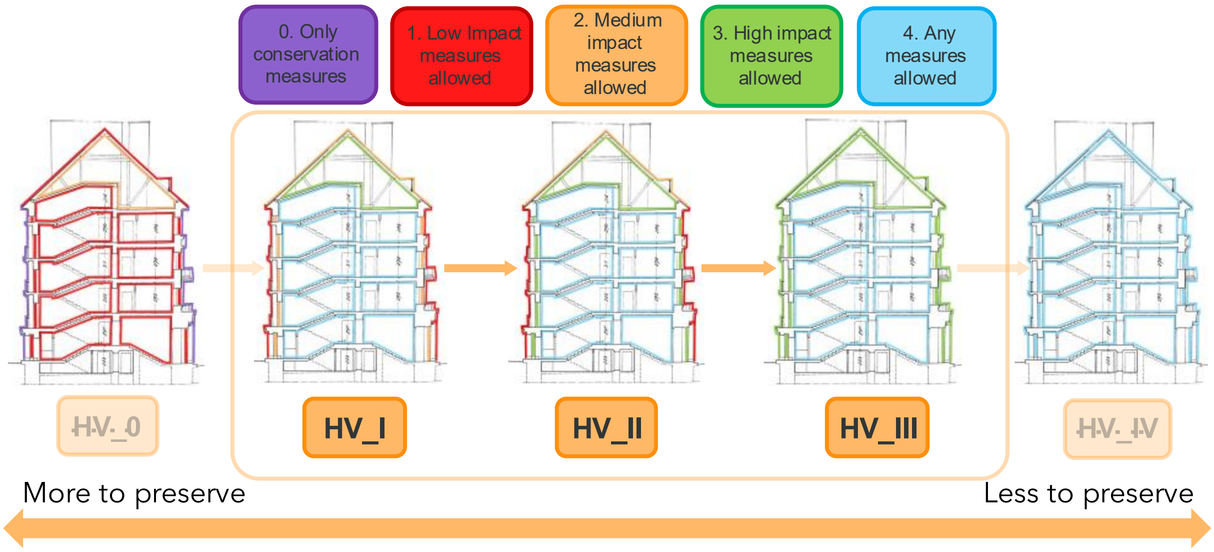


Figure 34: Overview of heritage value scenarios (EE)

HV_0. Highly valuable building as a whole

The building as a whole has significant heritage value, and few alterations have been made throughout its history. Therefore, the building envelope and interior must be entirely preserved, and only limited interventions are allowed.

For instance, damaged details may be replaced with copies; necessary modifications to comply with fire safety requirements may be implemented using specialised solutions; adaptations of living spaces for modern comfort are feasible; however, additional insulation is often not allowed.

This heritage scenario primarily applies to listed buildings, which are under national heritage protection. While all archetypes could potentially be listed as monuments, this scenario will not constitute the central focus of the HeriTACE project.

HV_I. Highly valuable façade and windows

In this scenario, the façade is of high value and numerous original valuable windows require conservation. The single glazing in the inner frame may be replaced with more energy-efficient double or triple glazing with or without new wooden frame depending on the thickness of the new glazing and the condition of the existing frame. Original outer frames are restored: damaged wooden parts and broken glazing replaced, and all glazing is resealed using window putty. Windows that have already been replaced must be substituted with copies of the original models. The visible roofing is also considered valuable.

Valuable case study buildings located in a milieu-valuable area have their exteriors protected. There may be valuable interior elements, but their preservation depends on the choices of the owner (legally not protected). This heritage value scenario is applicable to all selected archetypes in Estonia, but least common scenario today as only few buildings in the area still have original façade decorative elements and are usually better preserved over time.

HV_II Highly valuable facade with low value windows

In this scenario the highly valuable façade cannot be changed, but the windows have a low heritage value. Either these windows are too damaged to be preserved, or they have already been replaced with new ones made from different materials or featuring a different layout or details. The windows can be completely removed and remodelled since they are not original. However, new windows should be produced to match the original design. The visible roofing is also considered valuable.

Valuable sample buildings located in a milieu-valuable area have their exteriors protected. There may be valuable interior elements, but their preservation depends on the choices of the owner (legally not protected).

This heritage value scenario applies to all selected archetypes in Estonia. Replacing windows with new, inexpensive ones is often the first task many owners undertake (or wish to undertake) without consulting specialists. Original façade decorative elements are usually better preserved over time.

HV_III Less valuable façade and low value windows

The façade is less valuable (e.g. a simple plaster façade or wooden boarding without any decorative elements or mouldings) so interventions are possible. There may be several differently repaired or replaced parts and often the original windows have been replaced. High levels of deterioration and inappropriate staged works have significantly reduced the value of facades allowing more significant changes to improve energy efficiency of walls. Buildings located in a milieu-valuable areas have their exteriors protected at neighbourhood level and buildings in this category must keep the volume, structure and characteristic appearance of the archetype. While there may be valuable interior elements, their preservation depends on the choices of the owner (legally not protected).

This heritage value scenario is applicable for all selected archetypes in Estonia, as about half of the buildings have façades and windows in poor technical condition.

HV_IV. Building without heritage value

This is a scenario for a building without any heritage value, representing a more recent townhouse in the neighbourhood with the same typological structure. None of the case study buildings can be classified under this heritage value scenario.

5.4. Pre-renovation baseline scenarios

5.4.1. Use scenarios

Building use: function

In pre-renovation stage the buildings were used as apartment buildings. The attic and basement are unheated.

Comfort and temperature settings

Indoor temperature conditions in residential buildings constructed before 1990 are strongly dependent on the type of heating system in use. In buildings with wood-burning stoves–common in both wooden apartment buildings and smaller brick buildings–the indoor thermal environment is primarily determined by occupant behaviour, specifically their perception of thermal comfort and habits related to stove operation. Since stoves provide heat in discrete bursts and have limited thermal storage capacity, the timing and frequency of heating events directly affect the indoor temperature profile throughout the day. As a result, indoor temperatures can fluctuate considerably, both within a single day and between different apartments, reflecting individual preferences and heating routines.

In large brick apartment buildings, pre-renovation heating relied on high-temperature, single-pipe central heating connected to district heating via a substation. The design target was 21°C, but actual indoor temperatures varied widely—apartments near the heat source often overheated, while those at the end of the circuit remained cool, leading to uneven comfort.

As a baseline temperature set-point, a temperature of 21°C is assumed for all rooms in the apartment, for both pre-renovation and renovation scenarios.

5.4.2. Building envelope scenarios

<table>
<tr><th colspan="4">Pre-renovation: Building envelope scenario</th></tr>
<tr><td colspan="2">Scenario / archetype</td><td>BS1_PB
Wooden building</td><td>BS2_RB
Brick building</td></tr>
<tr><td rowspan="2">Walls</td><td>Facade</td><td>Horizontal log with ventilated cladding (either wooden or plastered)</td><td>Solid lime-sand or ceramic brick masonry wall, may have air cavity</td></tr>
<tr><td>Plinth</td><td colspan="2">Solid limestone masonry wall, plastered or unplastered exposed stone surface</td></tr>
<tr><td rowspan="2">Top boundary</td><td>Attic floor</td><td colspan="2">Wooden beams, sand or lightweight filling in between</td></tr>
<tr><td>Roof</td><td colspan="2">Cold attic and uninsulated roof</td></tr>
<tr><td rowspan="2">Floors</td><td>Basement floor</td><td colspan="2">Sand/earth</td></tr>
<tr><td>Basement ceiling</td><td colspan="2">Concrete slab</td></tr>
<tr><td colspan="2">Windows</td><td colspan="2">Double frame wooden 2-pane (original) windows</td></tr>
<tr><td colspan="2">Airtightness
q_{E50} $m^3/(m^2 \cdot Pa)$</td><td>10</td><td>5.5</td></tr>
</table>

Figure 35: Overview of Estonian pre-renovation building envelope scenarios.

During the Soviet occupation of Estonia, the archetypical buildings didn't receive much attention besides minimal maintenance, there was also constant shortage of goods, and the buildings were owned by the state. This means that by the beginning of 1990s when Estonia regained independence, the buildings were essentially either having the original building components or they had been replaced by the same type as the original.

BS1_PB: Wooden apartment building

This scenario applies to the pre-renovation state of the wooden apartment building archetype – the load bearing walls are either of wooden log or double plank type with ventilated cladding. The windows are either original (double wooden frame, both housing single glass pane) or Soviet era replacements of the same type. The top boundary of the heated volume is usually the attic floor made of wooden lightweight beams with lightweight filling or sand in between. The basement is unheated, and its ceiling is made of concrete slab, which may be supported by steel I-beams or railway rails within its volume. The foundation wall/plinth is made of limestone masonry which may or may not be plastered on the outside.

BS2_PB: Stalinist style brick apartment building

This scenario describes the envelope components of the brick apartment building archetype. The main differences compared to the BS1_PB are the wall type (brick masonry with or without an air cavity) and due to that, also the inherently higher airtightness. Windows are still either original or the same type as the original windows. The type is the same as those of the wooden buildings in scenario BS1_PB (double wooden frame, both have single glass pane), but here they typically have slightly different size and frame distribution.

5.4.3. Space conditioning scenarios

In their original state, wooden apartment buildings were heated by wood-burning stoves in each apartment, with no central heating. Heating was manually operated, and ventilation occurred naturally through building envelope leaks and openable windows, with air exiting via chimneys and entering through the structure, as fresh air valves were usually absent.

Brick buildings fall into two subtypes: larger ones had one-pipe central heating, typically connected to district heating or a local boiler, with natural or gravity-based ventilation shafts; smaller ones resembled wooden buildings, using wood stoves and lacking central heating.

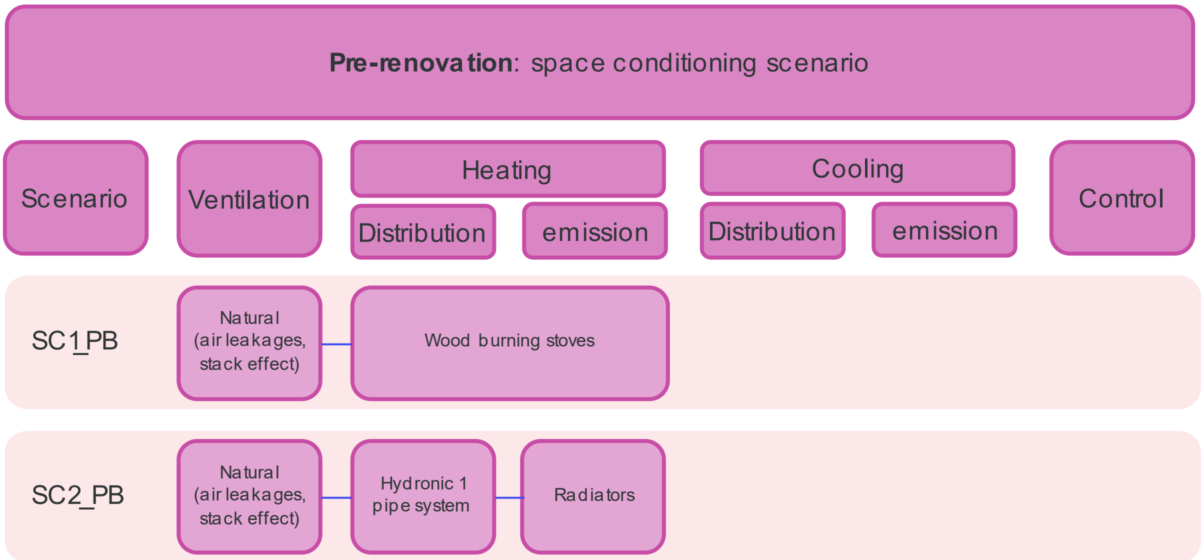


Figure 36: Overview of the pre-renovation space conditioning scenarios (EE)

Across all types, mechanical ventilation was generally absent, and air exchange depended on occupant behaviour and the natural air permeability of the structures.

In large brick apartment buildings, pre-renovation heating relied on high-temperature, single-pipe central heating connected to district heating via a substation.

In smaller brick and wooden buildings with stove heating, indoor temperature depended on occupant behaviour and stove-firing habits.

No mechanical cooling or central ventilation existed. Air quality depended on manual ventilation through window opening.

5.4.4. Energy scenarios

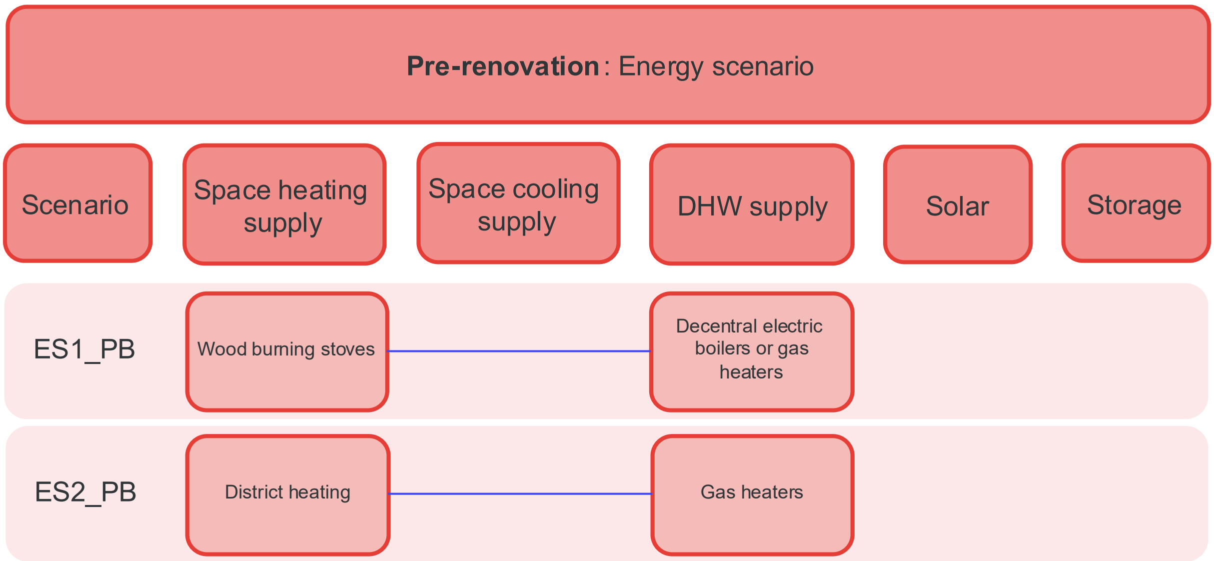


Figure 37: Overview of the pre-renovation energy scenarios (EE).

ES1_PB: Wood burning stoves and electric or gas heaters

This scenario applies to the buildings without connection to district heating network that had initially been built with wood burning stove heating. Domestic hot water is generated using decentral electric or gas heaters (if connected to gas network).

ES2_PB: District heating and non-condensing gas heaters

This scenario applies to the larger Stalinist style brick apartment buildings with connection to district heating and gas networks – the former is used for space heating and latter for domestic hot water generation.

5.5. Renovation baseline scenarios

5.5.1. Use scenarios

Apartment building (original)

Original heated area – no further changes besides combining smaller apartments to larger ones and removal of some interior walls.

Apartment building (expanded)

Attic & basement conversion: attic and basement have been converted to heated space (usually apartments) – this can help finance retrofit of the rest of the building.

5.5.2. Building envelope scenarios

Renovation: Building envelope scenario

Scenario / archetype		BS1RB Wooden building	BS2_RB Wooden building	BS3_RB Brick building	BS4_RB Brick building
Walls	Facade	Horizontal log with wooden cladding , interior insulation (ca 50% coverage)	Horizontal log with wooden cladding, exterior +interior insulation	Solid lime-sand or ceramic brick masonry wall, may have air cavity	Solid lime-sand or ceramic brick masonry wall, may have air cavity, ext. insulation 50 mm
	Plinth	Solid limestone masonry wall, plastered or unplastered exposed stone surface , additional insulation if existing plinth plastered			
Top boundary	Attic floor	Sand or lightweight filling between wooden beams, loose fiber insulation	Wooden beams, sand or lightweight filling inbetween	Sand or lightweight filling between wooden beams, loose fiber insulation	Wooden beams, sand or lightweight filling inbetween
	Roof	Cold attic and uninsulated roof	Insulated roof (attic converted to apartments)	Cold attic and uninsulated roof	insulated roof (attic converted to apartments)
Floors	Basement floor	Sand/earth	Concrete slab + insulation	Sand/earth	Concrete slab + insulation
	Basement ceiling	Concrete slab + insulation	Concrete slab	Concrete slab + insulation	Concrete slab
Windows		Original type windows + single frame 2-pane IGU windows (modern)	Mix on different windows (original type, various modern windows)		
Airtightness q_{E50}, $m^3/(m^2 \cdot Pa)$		9	7	4	4

Figure 38: Overview of Estonian envelope renovation scenarios.

BS1_RB: Wooden apartment building, low intervention

This scenario describes a renovation scenario where stepwise retrofitting has led to partial interior insulation, a mix of original type and modern (single frame, 2-pane IGU) windows and insulated top and bottom boundaries (basement ceiling and attic floor, respectively). Replacement of windows and partial insulation of exterior walls increases airtightness compared to pre-renovation state.

BS2_RB: Wooden apartment building, moderate intervention

This scenario builds on the previous one, however, here a mineral wool wind barrier board is used as exterior insulation in addition to the existing stepwise partially applied interior insulation. Due to attic and basement conversion to living space, roof and basement floor are insulated. As the insulation covers the whole wall envelope, airtightness is higher compared to the previous scenario.

BS3_RB: Brick apartment building, low intervention

Here the exterior surface has had no interventions besides stepwise replacement of windows, which results in a mix of various types with different thermal properties. The attic floor and basement ceiling are insulated. The airtightness of plastered masonry is significantly higher than that of the wooden buildings and slightly increased over the pre-renovation scenario due to replacement of windows.

BS4_RB: Brick apartment building, moderate intervention

A thin layer of insulation and plaster finishing is added to the exterior surface. Similarly to the previous scenario, the windows are a mix of various types with different thermal properties. Due to attic and basement conversion to living space, roof and basement floor are insulated. The airtightness is on the same level as in the previous brick building scenario.

5.5.3. Space conditioning scenarios

In many wooden and smaller brick apartment buildings, original stove heating remains partially or fully in use, especially where renovations have been minimal. To meet higher comfort and efficiency demands, various supplementary systems have been introduced.

Apartment-based gas boilers are among the most common upgrades, providing water-based radiator heating with individual control. These are especially prevalent in buildings lacking central heating. Electric radiators and air-to-air heat pumps are also widely used—either as primary or supplementary heating—offering low-cost installation and, in the case of heat pumps, cooling as well.

Ventilation remains mostly natural, relying on window airing and passive stack ventilation, often inadequate during the heating season. Only fully renovated buildings typically feature mechanical ventilation with exhaust or heat recovery systems.

Larger brick buildings with one-pipe district heating generally remain connected to the network. Some have been modernized with thermostatic radiator valves, heat cost allocators, or conversion to two-pipe systems for better control and comfort.

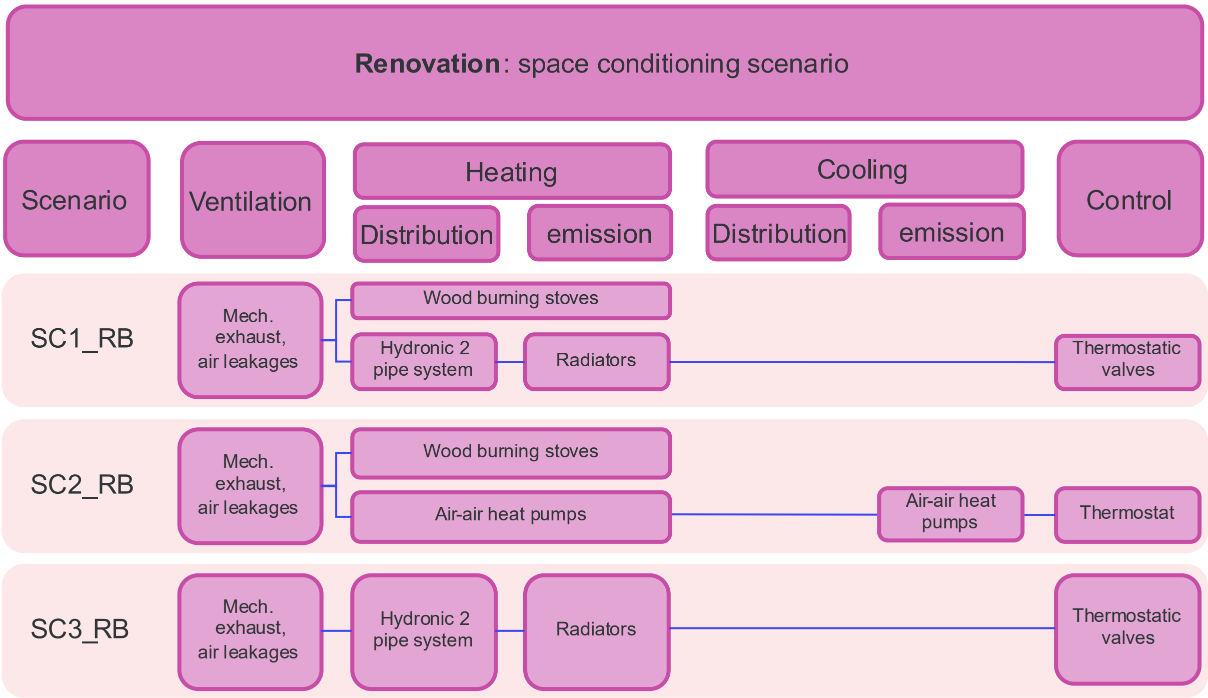


Figure 39: Overview of the space conditioning renovation baseline scenarios (EE).

Energy renovation in large brick apartment buildings has focused on modernising central heating systems, particularly by replacing single-pipe layouts with more efficient two-pipe hydronic systems and adding thermostatic radiator valves, resulting in better temperature control and reduced thermal imbalance.

5.5.4. Energy scenarios

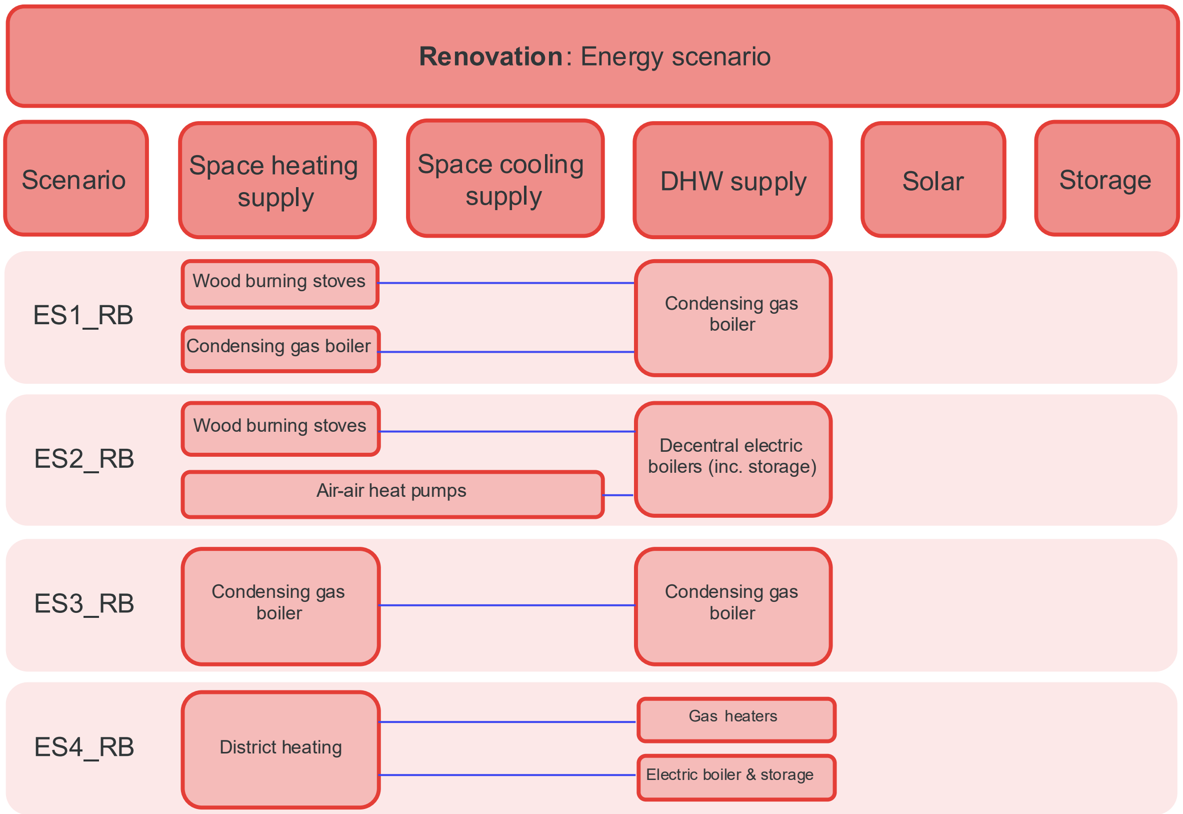


Figure 40: Overview of the energy supply renovation baseline scenarios (EE).

ES1_RB: mix of wood burning stoves and gas boilers

This scenario applies to smaller buildings with access to gas network. Stepwise retrofit has resulted in partial conversion to apartment-based condensing gas boilers for both space heating and domestic hot water generation. Some apartments fully or partially still use wood burning stoves for space heating.

ES2_RB: mix of wood burning stoves and electric heating

This scenario applies to smaller buildings without access to district heating and gas networks. Stepwise retrofit has resulted in partial adaptation of air-air heat pumps for space heating in some apartments while others still use wood burning stoves. Domestic hot water is generated using decentral electric boilers.

ES3_RB: gas boilers

Here the whole building has converted to apartment-based condensing gas boilers for space heating and domestic hot water generation.

ES4_RB: district heating and mix of gas & electric boilers

This scenario applies to larger buildings with access to district heating and gas networks. The space heating is still supplied by district heating, while the apartment-based gas heaters for domestic hot water generation may have been partly replaced by electric boilers.

6. Italy: baseline scenarios

6.1. Overview

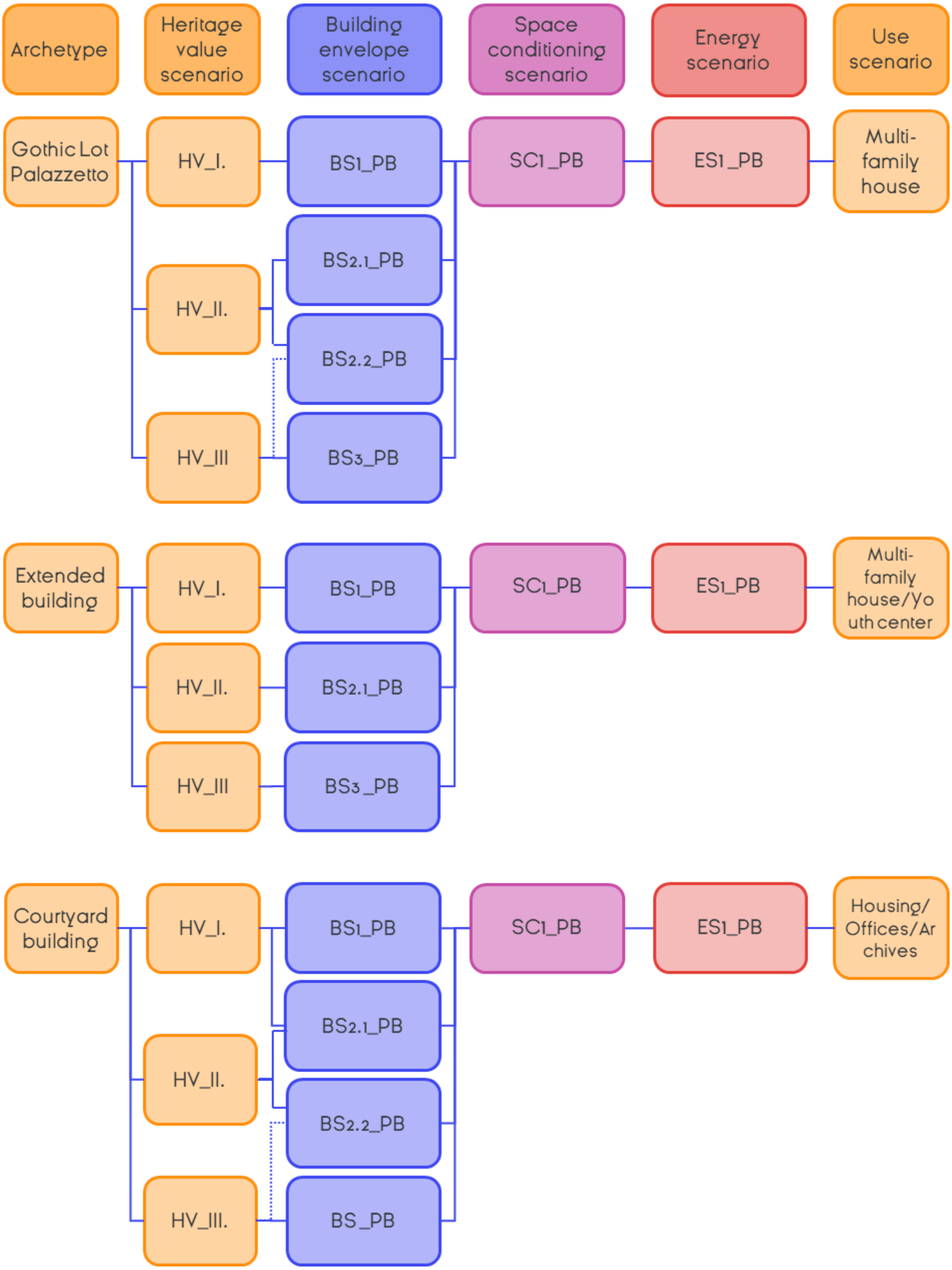


Figure 41: Overview of the pre-renovation baseline scenarios (IT)

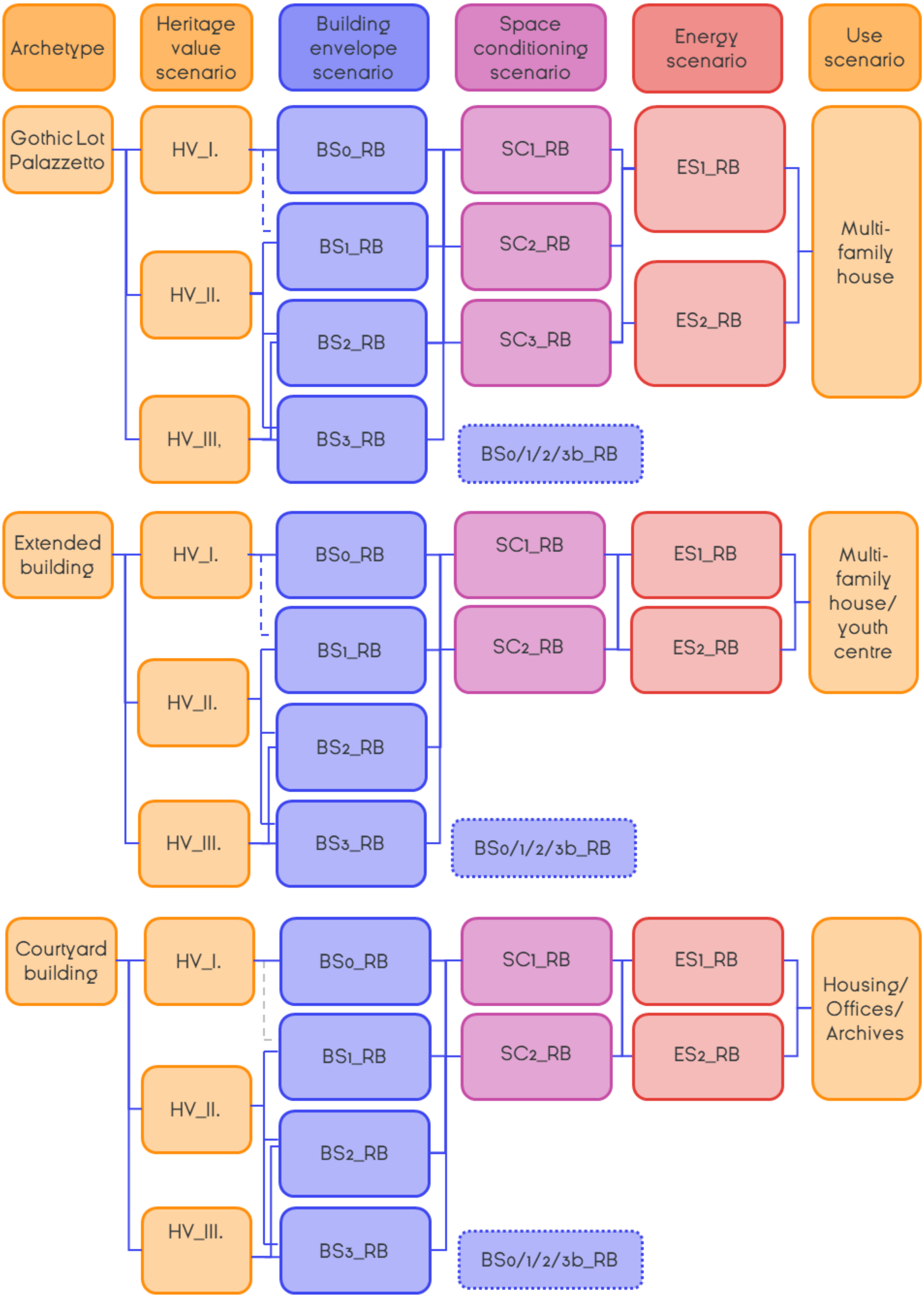


Figure 42: Overview of the renovation baseline scenarios (IT)

6.2. Archetypes

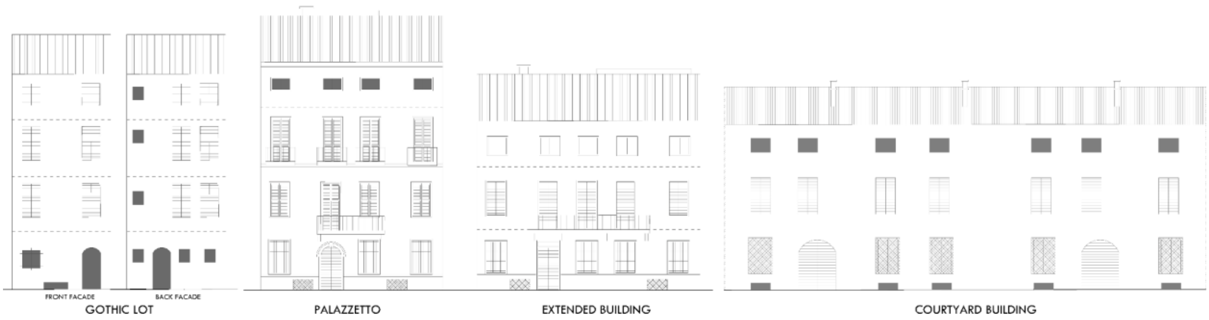


Figure 43: Overview of townhouse archetypes by facade (IT)

The most common building archetype at neighbourhood scale in Mantova is the **Gothic lot,** a typical medieval townhouse with a narrow street-facing facade and greater depth, often featuring three floors and a rear courtyard used for hygiene and domestic activities. Its layout is functional, with stairs positioned either centrally or along the length, and includes light wells to improve natural lighting.

The **Palazzetto** archetype defines, instead, 17^{th} – 19^{th} century buildings that resembles a Gothic lot but with a greater width, often with three or four floors including a mezzanine and basement. It includes a noble floor with higher ceilings, a rear courtyard, and sometimes L-shaped extensions. It reflects later historical evolutions and renovations.

Another Mantovan building archetype is the **Extended building**, or houses in line. It results from merging multiple Gothic lots. These buildings have wider, often irregular facades with multiple entrances, including carriage access, and feature more symmetrical internal layouts.

Finally, **Courtyard buildings** represent a larger and more complex Mantovan archetype, characterized by more refined structures built around an internal courtyard. They typically have two or three levels and multiple staircases separating noble and service areas, showing a complex internal organization due to historical layering.

6.3. Heritage value scenarios

Five heritage value scenarios were identified for the Italian townhouse archetypes (see

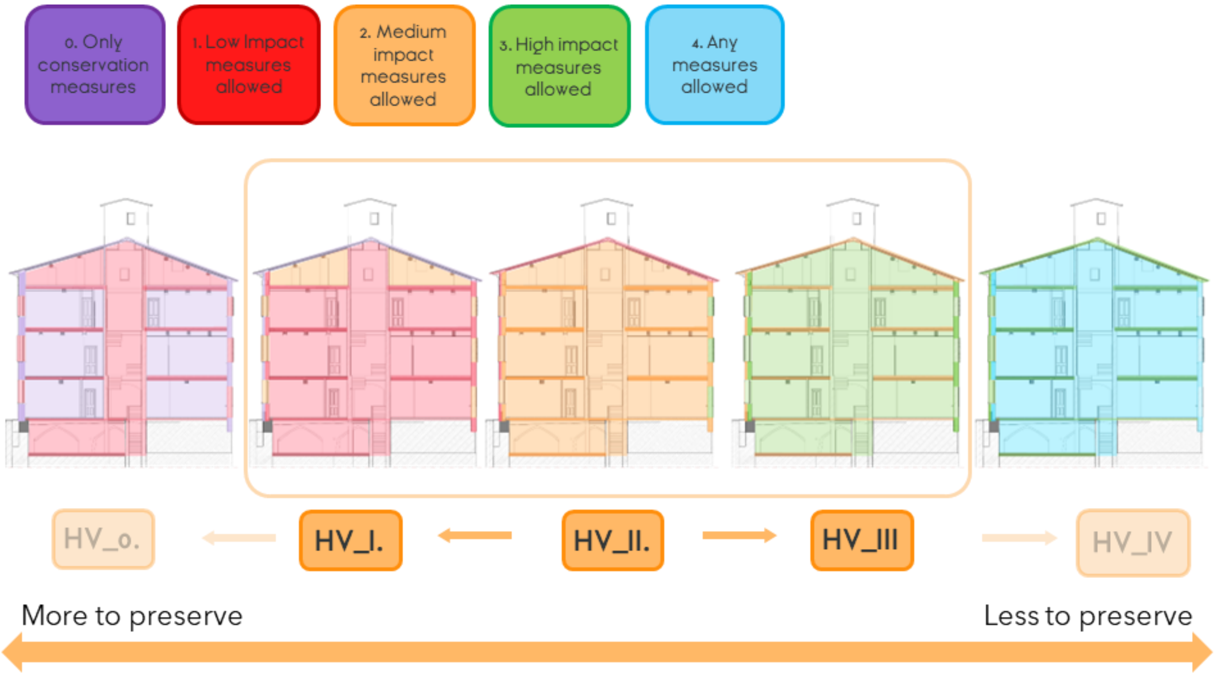


Figure 44), ranking from scenario HV_0 with the highest heritage value to HV_IV without heritage value. The HeriTACE project focuses on the HV_I – HV_III scenarios, that are the most representative and replicable for the heritage townhouse archetypes. In

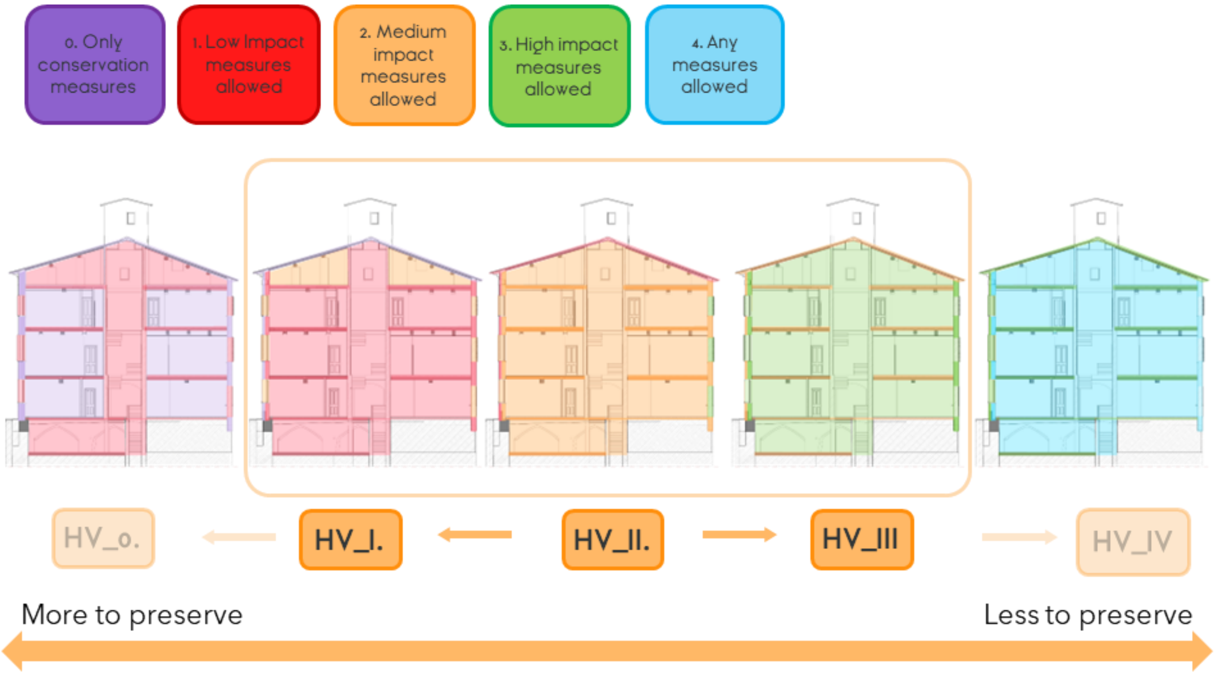


Figure 44, for each heritage value scenario, the building sections indicate the heritage value categories (as explained in section 2.4.2) that apply to each building component. The section of the gothic lot is used as example.

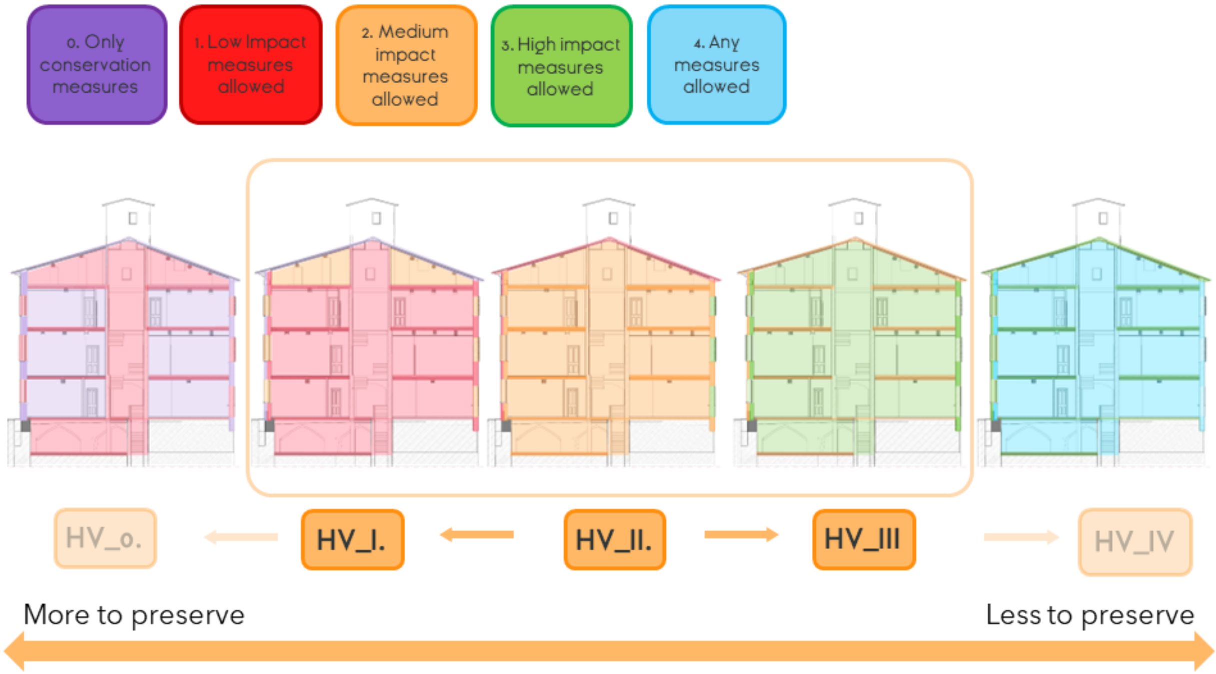


Figure 44: Overview of heritage value scenarios (IT)

HV_0. Highly valuable building as a whole

The building envelope and interior must be preserved in their entirety (both exterior elements and interior ones). The building holds significant heritage value, and few modifications have been made throughout its history. Consequently, only limited interventions are allowed (Category 0 and Category 1 apply to most elements). The post-renovation condition will closely resemble to preserve the historical material consistency. For instance, restoration activities are indicated to recover damaged parts and to solve decay problems; necessary modifications to comply with use and safety requirements may be implemented using minimum and (as much as possible) reversible solutions, according to heritage preservation experts' opinion; additional insulation or substitution of parts is not usually permitted.

This heritage scenario primarily applies to monumental, listed buildings, which are under local heritage protection and where eventually the changes of building function during time did not affect either the exteriors and the interiors. In the HeriTACE project, this scenario will not be applicable.

HV_I. Highly valuable building with typical interior elements that should be preserved

This scenario includes all building with valuable exterior façades, where original windows/shutters require preservation and restoration, and typical interior elements have been object of small renovation/modifications linked to the construction use during its history. In this heritage scenario, the windows in the front façade cannot be changed because of their recognised heritage value or because they are found valuable by the owners or designers. The back façade has low heritage value as a whole, however, the single glazing in the inner frame may be replaced with more energy-efficient double or triple glazing (recovering the original window frame). Windows that have already been replaced may be substituted with more performant copies of the originals. The visible roofing is also considered valuable and only repairing and maintenance may be accepted.

About interior elements, they should be preserved and may be retrofitted only with small changes, accordingly with the choices of the owner/ local heritage protection regulations. Small/medium retrofit interventions in secondary spaces (e.g. staircase, basement, attic) may be considered feasible if there are not decorations or elements to be preserved.

This heritage value scenario is applicable usually when high level protection regulations are in force, so exterior facades were preserved, and only small changes occurred in the interiors. This situation may be applicable also in listed buildings, where architectural changes were assumed as corresponding to one phase in the building history timeline.

HV_II Valuable building with partially modified elements

This heritage value scenario is quite common in landscape valuable area where exteriors may be protected, and urban regulation is not too much stringent on interior courtyards and back facades, with low heritage value that can undergo medium impact interventions (category 2). While original façade decorative elements are usually preserved over time, if the exterior plaster results to be damaged, its substitution (with one similar to the historical existing one) may be accepted by local heritage authorities. Retrofit medium impact modifications of the interior facades are also accepted, if they are considered compatible with the historic fabric. The visible roofing is also considered valuable; however, interventions from the inside may be accepted. There may be several differently repaired or replaced parts of the interior elements and their preservation depends on the choices of the owner.

HV_III Valuable building already object of renovation

The building is not listed, and its façade has been object of interventions during time (e.g. a more recent plaster façade without any decorative elements or mouldings), so also high impact interventions are possible (Category 3). In this case, replacing windows with new, inexpensive ones is often the first task many owners undertake (or wish to undertake) without consulting specialists; so, they can be changed with more performant and harmonizing ones. While there may be valuable interior elements, their preservation depends on the choices of the owner. In many cases, huge changes in the interior dating back to the past of the construction are detectable.

HV_IV. Townhouse without heritage value

This is a scenario for a building with no specific heritage value, representing a more recent townhouse in the historic neighbourhood replicating the same typological structure. This scenario is included in the list for providing a complete overview of scenario's that occur for the considered archetypes but is not in scope of the HeriTACE project.

6.4. Pre-renovation baseline scenarios

6.4.1. Use scenarios

Building use: function

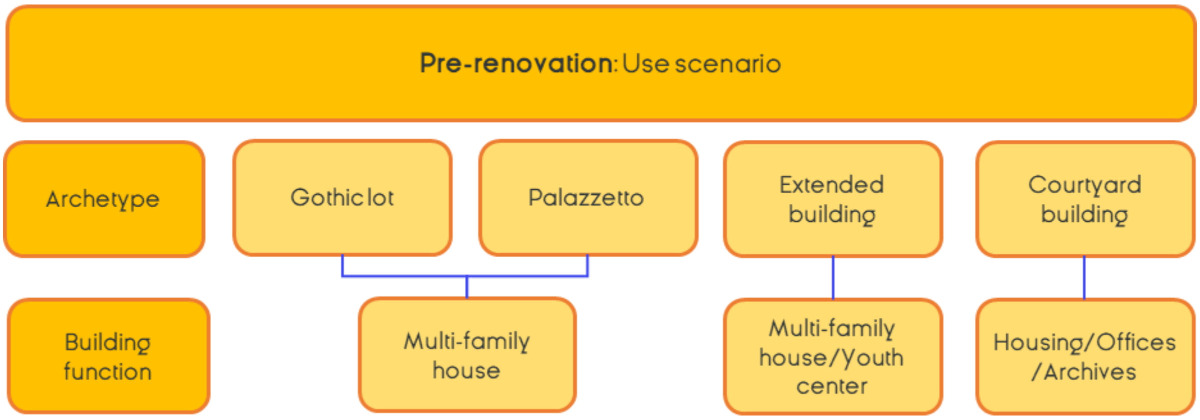


Figure 45: Pre-renovation Use scenario's (IT)

In the pre-renovation baseline, the Gothic lot and Palazzetto are both considered multi-family house. The attic and basement are generally not in active use and serve primarily as storage or technical spaces. The Extended building archetype has greater spatial flexibility, making it suitable for combined functions such as residential units and community facilities, including youth centres. Similarly, the Courtyard building archetype is characterized by its adaptability to complex programs, accommodating not only residential spaces for short/long periods but also office spaces and archival functions. Even in these cases, attic and basement spaces are mainly used as storage or technical spaces.

Comfort – temperature settings (heating and cooling)

For all the archetypes the setpoint temperature during the heating period is 20°C (from October 15 to April 15) for 14 hours per day. Given the presence of thermostatic valves in the radiators, the temperature can increase by a few degrees in each room according to the user's need. Regarding the summer season, the cooling system can be activated at any time it is needed, normally with a setpoint of 26° C. However, not all rooms are equipped with air conditioning splits. It should be noted that even in unconditioned cases the conditions above described can be considered valid.

6.4.2. Building envelope scenarios

Pre-renovation: Building envelope scenario

Scenario		BS1_PB	BS2.1_PB	BS2.2_PB	BS3_PB
Walls	Front facades	Raw brick masonry (more than 40 cm) with exterior and internal plaster/cladding			
	Back/ Courtyard facades*	Raw brick masonry (more than 40 cm) with exterior and internal plaster/cladding			
Top boundary	Pitched roof	Wooden roof with wooden planking, joists and wooden beams with a circular section. External cladding in (antique or new) tiles.			New roof structure with interior insulation. External cladding in new tiles.
	Upper most floor	Unused attic space. *Uppermost floor* composed of wooden floorboard resting on a framework of joists and main beams. Ceiling side made of reed and plaster.			Reinforced mix wooden floorboard. cladding in new terracotta tiles.
Floors	Ground-floor	Tiles on sand bed (if not on a cellar)			Tiles on an insulated new slab (if not on a cellar)
	Basement ceiling	Masonry ground floor slab (sometimes on vaults). cladding in terracotta tiles/stone			Masonry new ground floor slab (sometimes on vaults)
Windows	Front windows	Original wooden frame Single glazing		Standard double-glazed windows	
	Secondary (back/courtyard/already changed /annex) windows*	Original wooden frame Single glazing	Standard double-glazed windows		
Shading		Original interior /exterior wooden shutter	Original exterior façade wooden shutter + new shutters on the back/courtyard		New shutters
Airtightness		n50=7.5	n50=6	n50=4.5	

* where applicable

Figure 46: Pre-renovation building envelope scenario's (IT)

There are four different building envelope scenarios for the pre-renovation baseline (with three main divisions and one subdivision): Two main scenarios with little intervention which differ mainly in whether and how windows have already been replaced. The third main scenario includes interventions on the top and lower boundary of the envelope. What they do have in common is that the walls of the front and back facades are in all scenarios solid masonry walls made of raw bricks with interior lime plaster and exterior lime plaster. The attic is in most cases unused, which makes the uppermost floor the thermal envelope – it is composed of wooden floorboard resting on a framework of joists and main beams and the ceiling side is made of reed and plaster. On the bottom the basement ceiling forms the thermal envelope, which cement tile or wooden flooring on a masonry slab, often also on vaults. There are also cases without cellar, where the tiles lay on sand bed. Original windows are single windows with wooden frame and single glazing, they have however often already been replaced, which is considered in BS2.1 (part changed) and BS2.2 and BS3 (all changed). Since the airtightness is connected to the windows, these values vary accordingly. All typologies do have wooden shutters. In the definition of these scenarios, priority has been given to the characteristics influencing the energy performance. They are applicable to all typologies.

More detailed versions of the above scheme, including also information on originality and conservation status of materials which do not influence the energy performance (e.g. roof tiles, plaster, etc.), but are important for the selection of interventions are reported in 'D2.1 Building envelope characteristics'. Those schemes are also reported separately per typologies and do point out the peculiarities of those and do include aspects like interior decorations, intermediate floor, courtyard elements.

BS1_PB Original windows

Building envelope scenario 1 depicts the most unchanged version of these buildings, where all the windows are still the original wooden windows frames with single glazing.

BS2.1_PB Original windows in the front facade

Building envelope scenario 2 considers buildings, where (part of) the windows have been changed, but no other intervention on the envelope has been done yet. Scenario 2.1 considers hereby that part of the windows has been replaced with double glazed windows – for the Gothic Lot, Palazzetto and Courtyard Building these will usually be the backyard/courtyard windows. In the Extended Building typology which do not have such a differentiation of facades it just considers part of the windows having been changed (which might depend of the function of the room, visibility but also ownership …)

BS2.2_PB All windows double glazed

Building envelope scenario 2.2 corresponds to 2.1 except that all windows have been replaced with double glazed windows.

BS3_PB Roof and ground floor insulated

Building envelope scenario 3 depicts a status with slightly more changes: besides all windows having been changed to double glazing it also considers that the roof and ground floor have been changed: the roof has already been refurbished or even replaced, including a small addition of insulation, or the uppermost ceiling has been reinforced and might in this case also include an insulation layer. Also, the ground floor either got a new slab on sand bed with a bit of insulation, or if the building has a cellar the masonry slab has been insulated (from above, if there are vaults).

6.4.3. Space conditioning scenarios

In all Italian archetypes, no particular difference is revealed. For this Pre-renovation baseline, in all the archetypes the heating system relies on a central hydronic distribution network, which supplies high-temperature radiators. The indoor environment is regulated through a central thermostat in combination with thermostatic radiator valves, allowing for basic zone-level temperature control. This configuration reflects a conventional approach typical of older, pre-renovation dwellings, characterized by limited automation and reliance on user-operated components. A cooling system or whole building (mechanical) ventilation system is not present, therefore, to supply fresh air the only solution is to use the openable windows in all the rooms. In the Figure 47, an overview of the pre-renovation baseline for all the archetypes is given.

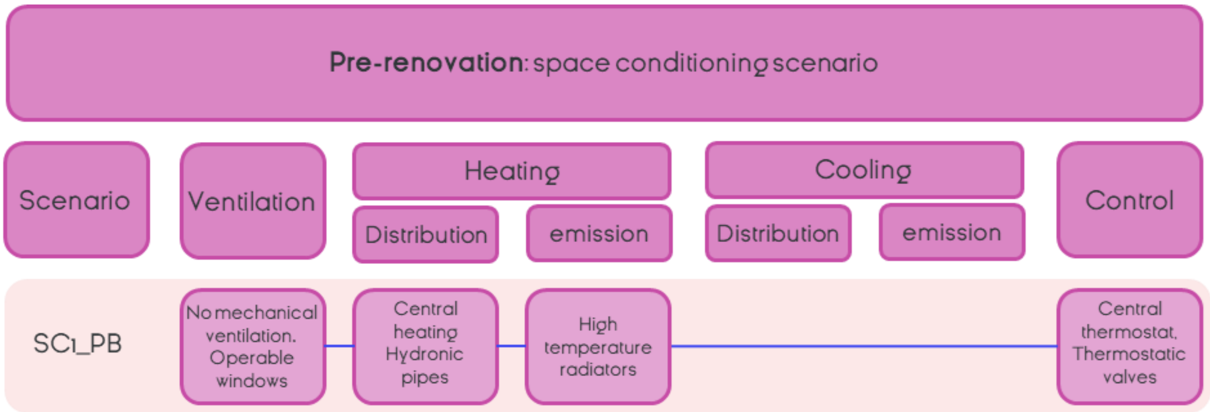


Figure 47: Schematic overview of the Pre-renovation Baseline (PB) Space conditioning (SC) scenario

6.4.4. Energy scenarios

The pre-renovation energy scenario for all Italian archetypes no particular difference is revealed. Has been identified one energy scenario.

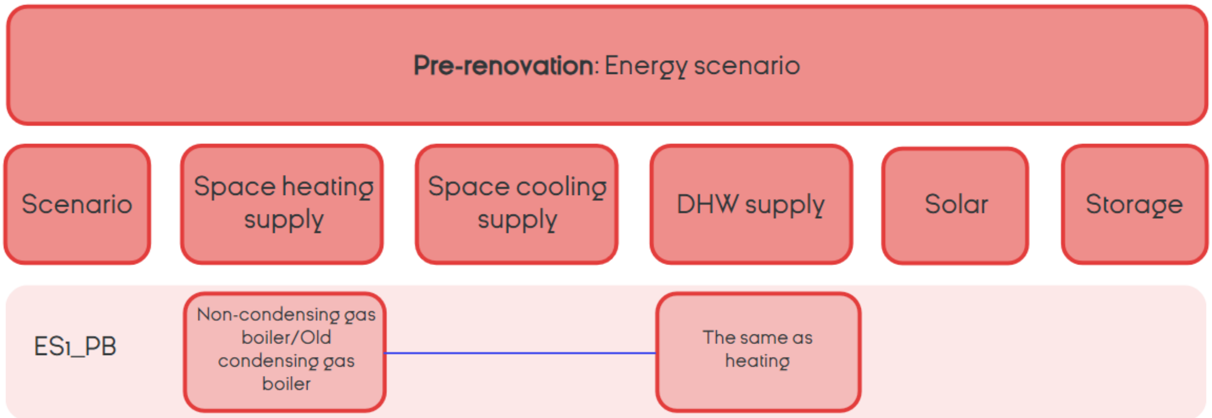


Figure 48: Schematic overview of the Pre-renovation Baseline (PB) Energy Scenario (ES)

ES1_PB Non-condensing/old condensing gas boiler

In Scenario ES1_PB, space heating is provided by a non-condensing or condensing gas boiler, representing a conventional and relatively inefficient technology. This same system is also used to supply domestic hot water (DHW), indicating a shared thermal source for both services. No systems are available for space cooling, solar energy and thermal storage.

6.5. Renovation baseline scenarios

6.5.1. Use scenarios

Building use: function

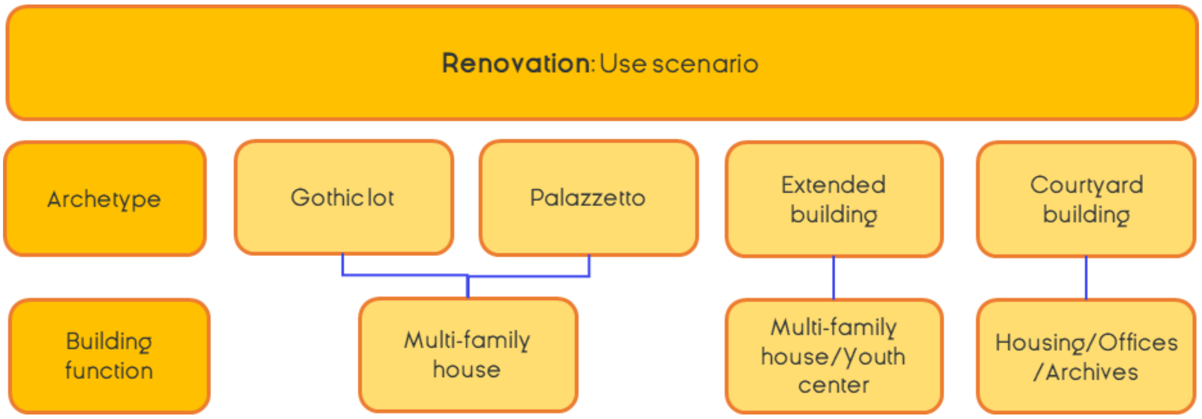


Figure 49: Renovation Use scenarios (IT)

The building function are the same as the pre-renovation baseline. The only variation is that in the renovation baseline the attic could be used as residential space after appropriate insulation of the envelope and implementation of an air conditioning system.

Comfort – temperature settings (heating and cooling)

The temperature settings for heating and cooling are the same as the pre-renovation baseline. The only variation is that in the baseline renovation the air conditioning system can be implemented in all rooms that need it (for example, if the attic is used as a residential space).

6.5.2. Building envelope scenarios

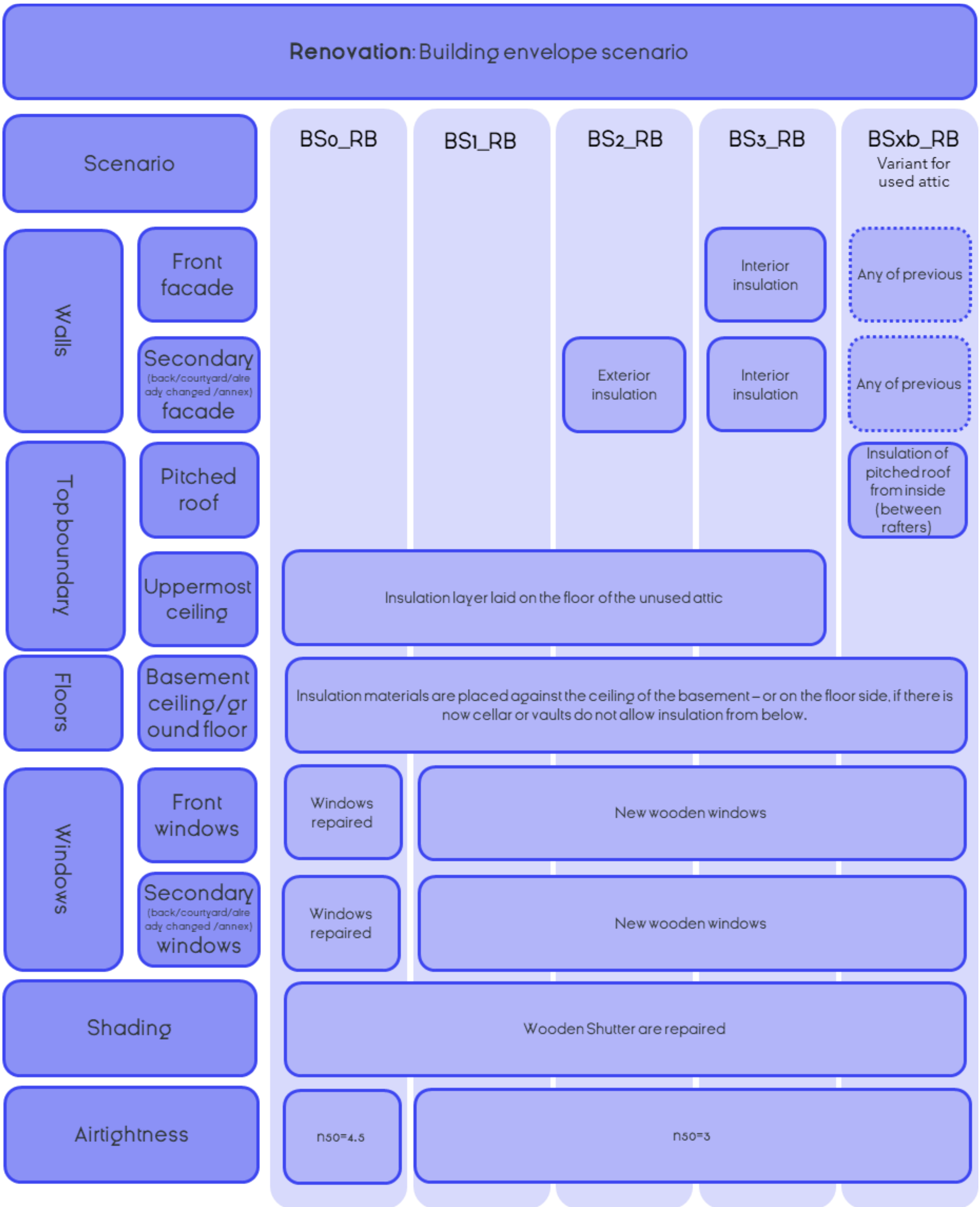


Figure 50: Renovation building envelope scenarios (IT)

The Renovation scenarios for the envelope retrofit which take up the Business-as-Usual scenarios from D2.2 differ mainly in how the walls are insulated (scenarios 1, 2 and 3). In comparison to D2.2 a Scenario 0 is introduced with no changes on the windows and a scenario where the attic is transformed from an unused to a used space (scenario option b, applicable to 0 to 3).

Common elements are

- Insulation of the **ground floor** - insulation materials are placed against the ceiling of the basement. If there is no cellar or if vaults do not allow insulation from below, the floor is insulated between the joists and beams from above.
- Insulation of the **unused attic** with an insulation layer laid **on the attic floor** which keeps the roof itself untouched. The chimney/ventilation tower has to be considered separately
  [Scenario b considers a **change in use of the attic to living space** – and respective insulation of the roof between and/or below the rafters]
- Replacement of the **windows**, be the original or already changed some decades ago, with wooden double-glazed windows.
  [BS0_RB considers the front windows not being changed]
- This change together with the at least partial work on the plastering and the insolation basement and uppermost ceiling will lead to **increased airtightness**.
- The **shutters** and existing **shading system** are sometimes repaired, more often replaced – but from an energy performance point of view this is less important than the fact that they are not disused.

Where the scenarios differ, is mainly whether and how the walls are treated.

BS0_RB Intervention only on attic and basement ceiling

For Heritage Value Scenario HV_I a renovation baseline scenario without the replacement of the windows has been defined. The only intervention considered here is insulating the Ground floor and the Attic – be it the attic floor or the pitched roof in case the attic is transformed to living space.

BS1_RB Neither front nor back façade are insulated

All the other renovation baseline scenarios have in common, that windows are replaced with (more or less conservation compatible) new (replica) windows. It is however still quite common not to intervene at all on the walls, wherefore it is included as a baseline here. This solution increases the risk of mould growth if moisture is not control via (natural or mechanical) ventilation or adequate use.

This scenario can be applied to buildings with HV_I only if windows have already earlier been replaced (!) and is typically applied to HV_II where the replacement of windows is usually permitted and original facade decorative elements have been preserved.

BS2_RB Front façade not insulated, exterior insulation on back façade

In this renovation baseline scenario windows are again replaced, the protected front façade is not insulated (especially, if the interior is decorated, and the exterior also protected), but the back façade and or annexes from later period are insulated from the outside. The new windows of the back façade can in this case be positioned in the insulation layer level, but this step is often not done.

This scenario is typically applied to buildings with HV_III which are not listed and where the facade is considered less valuable. These buildings have often been changed over time, especially their back side, annexes might have been added etc.

BS3_RB Front and back façade with interior insulation

In this renovation baseline scenario windows are again replaced, the same interior insulation system is applied to both front and back façade. The type of interior insulation system can vary within this renovation baseline: both mineral wool with vapour barrier and capillary active system with e.g. calcium silicate are found.

With interior insulation the thermal inertia of the respective wall is not any more available for mitigating overheating in summer. However, historic buildings do also have considerable mass in partition walls and ceilings. Whether these are enough will be investigated in the simulation studies.

This scenario is typically applied to buildings with HV_II, where the original facade decorative elements have been preserved, but also to HV_III buildings, if whole building retrofit including the front facade is envisaged.

BS0b_RB/ BS1b_RB/ BS2b_RB/BS3b_RB Attic Use

When the attic is transformed into living space, the roof itself is insulated. This is considered as separate variant, as it influences the energy performance in kWh/m²: The surface to volume ratio of the building decreases and this will result in better overall energy performance per m².

6.5.3. Space conditioning scenarios

As the pre-renovation space conditioning baseline in all archetypes are similar, also how these are renovated is similar.

Figure 51 illustrates the renovation space conditioning scenarios SC1_RB, SC2_RB and SC3_RB, outlining the modifications implemented in ventilation, heating, cooling, and control systems. In both scenarios SC1_RB and SC2_RB, ventilation remains unchanged from the pre-renovation condition, relying solely on natural ventilation through operable windows, with no mechanical systems installed. Heating continues to be delivered through a central hydronic distribution system. In SC1_RB, the existing high-temperature radiators are retained, while in SC2_RB, they are replaced with new and more efficient high-temperature radiators, indicating an upgrade in the emission system.

The SC3_RB scenario introduces a passive ventilation strategy. Specifically, for this scenario renovation baseline, it is proposed to use the staircase as a wind tower, as there is an opening on the top that enhancing natural air movement through stack effect. This strategy aims to reduce the reliance on mechanical systems, improving energy efficiency while maintaining indoor air quality through architectural means. The heating and cooling system is the same as scenario SC2_RB.

A cooling system, which was previously absent, is introduced in all three renovation scenarios. It is distributed through local cooling tubes and emitted via a multi-split system, representing a significant enhancement in thermal comfort capabilities. The control strategy is also modernized: the scenarios include a central thermostat with a heating curve and thermostatic valves for regulating heating, while cooling is managed manually. This setup reflects a transitional phase toward more efficient and responsive environmental control, while still maintaining some degree of user interaction.

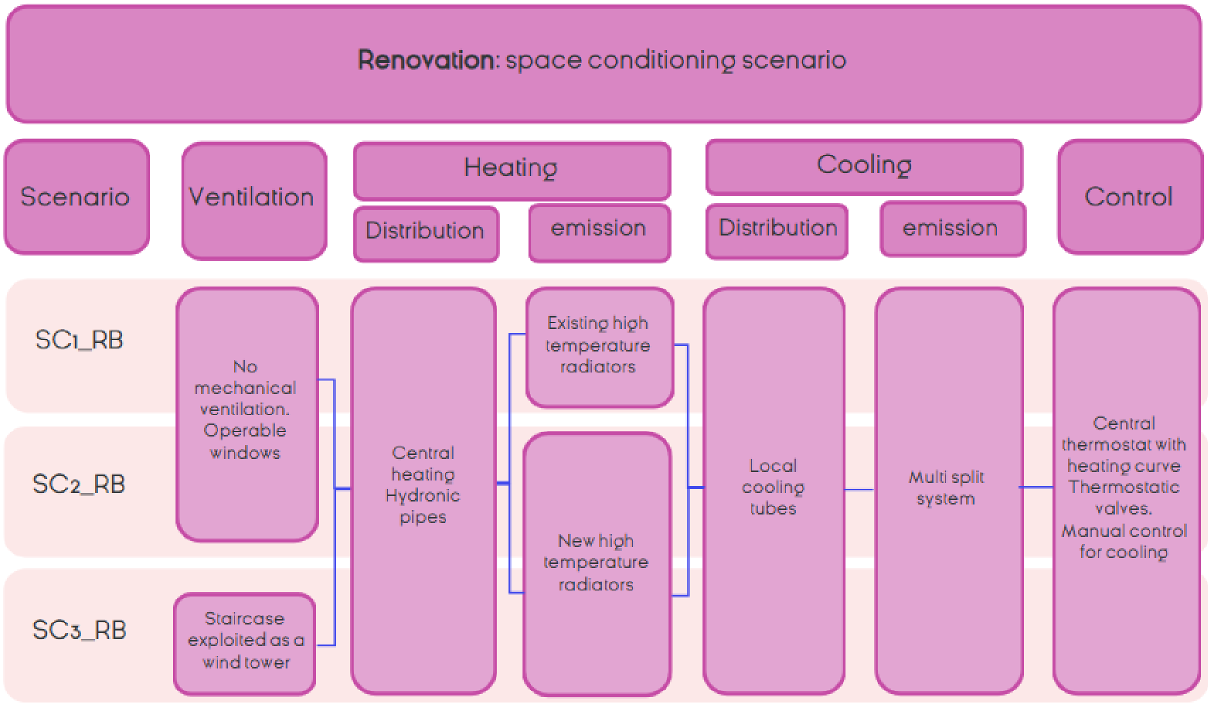


Figure 51: Schematic overview of the Italian Renovation Baseline (RB) Space Conditioning scenario's

6.5.4. Energy scenarios

The Figure 52 presents the energy system configurations adopted in the post-renovation phase for two representative scenarios (ES1_RB and ES2_RB).

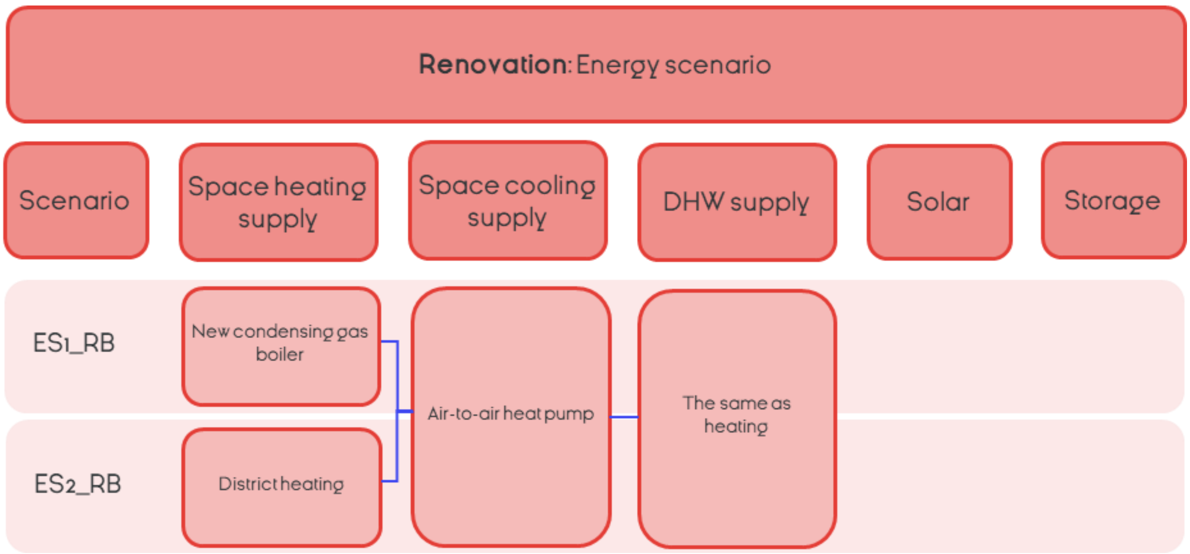


Figure 52: Schematic overview of the Renovation Baseline (RB) Energy Scenario (ES)

ES1_RB New condensing gas boiler, air-to-air heat pump

A space heating is supplied by a new condensing gas boiler. A space cooling is provided through an air-to-air heat pump. The domestic hot water supply remains coupled with the space heating system, following the same configuration as the heating source. As in the pre-renovation stage, solar energy systems and storage solutions are not implemented or explicitly considered in these scenarios, suggesting a limited integration of renewable or auxiliary energy sources at this stage of renovation.

ES2_RB -District heating, air-to-air heat pump

A district heating network is utilized. A space cooling is provided through an air-to-air heat pump. The domestic hot water supply remains coupled with the space heating system, following the same configuration as the heating source. As in the pre-renovation stage, solar energy systems and storage solutions are not implemented or explicitly considered in these scenarios, suggesting a limited integration of renewable or auxiliary energy sources at this stage of renovation.

7. Conclusion

7.1. Results and conclusions

The baseline scenarios define the situation of the heritage building as starting point for the HeriTACE renovation approach and represent the reference situations of the building for assessing the performance indicators, i.e. to compare the situation 'before' and 'after' a HeriTACE renovation. In this report two baselines are defined for comparison to the HeriTACE renovation approach:

- The **pre-renovation baseline** represents the situation of the heritage townhouse before a renovation takes place. In the HeriTACE project, it is defined as the reference situation of the building as in the *present state, assuming no recent renovation* has taken place to implement a range of recent EPBD-inspired energy renovation measures. This corresponds to the situation of a building in which the last renovation dates from the period 1990-2010.
- The **renovation baseline** documents a *renovation according to common practice today*, where the elements are renovated step-by-step with common practice renovation solutions, and fulfil the local temporary energy-related requirements, such as requirements related to the local EPBD implementations and heritage restrictions.
- The **HeriTACE renovation approach** developed in this project, represents *future-proof renovations* in line with the most recent developments of energy renovations and while maintaining the heritage value. Whether they are executed as a one-step deep renovation, or as stepwise measures, the HeriTACE renovation scenarios provide a complete and optimised plan of energy measures that all together aim at a significant energy use reduction and use 100% fossil-free energy sources in the building and neighbourhood.

The high-level pre-renovation and renovation baseline definitions are applied to the various HeriTACE archetypes by specifying the baseline architectural and use characteristics and building-technical characteristics. The group of architectural and use characteristics starts with the different heritage townhouse **archetypes**, that were specified per climate-zone (or country) in D5.1, including four Belgian, one Norwegian, four Estonian and four Italian townhouse archetypes.

For each archetype building **heritage value scenarios** are defined, that describe the characteristics of the archetype related to its architectural and heritage value. The heritage value scenarios range from scenarios where the building as a whole has significant heritage value and only limited interventions are allowed (typically applying to a selection of listed heritage buildings), to scenarios for buildings with low or no heritage value, where few restrictions apply. The HeriTACE project mainly focuses on the scenarios in between these extremes, that represent the majority of townhouses with heritage value, where various degrees of restrictions apply with regard to conservation and renovation measures. For each building heritage value scenario, the allowable measures for all building components is specified. In order to apply a uniform approach for the various countries involved, the generalised heritage value categories of allowable measures at building component level, that were defined in collaboration with T5.1 (see D5.2), are applied. These five categories cover the spectrum from very strict conservation (where only conservation measures are allowed) to no heritage restrictions (where any renovation measures are allowed) at building component level.

Furthermore, one or several **use scenarios** can be identified for each archetype, describing the function of the building and user-related characteristics. Townhouses were originally constructed with a primarily residential (single- or multi-family) function, sometimes including secondary small commercial or office functions. This remains the primary use in more recent times as represented in the pre-renovation and renovation baselines, although for some archetypes there are typical changes from single- to multi-family functions, or changes to office or commercial functions. The building user-related characteristics mainly focus on occupation patterns and user behaviour related to the conditioning of the building. For the baseline scenarios, one typical design occupation of the building is chosen per country assuming contemporary comfort requirements that are the result of a typical use and temperature settings for the HVAC systems.

The building-technical characteristics describe the properties of the building envelope, the space conditioning systems and energy systems. As they can also be different for the different archetypes or different heritage value and use characteristics, they are also grouped into scenarios. The baseline scenarios are selected based on the analysis of case-study townhouses in the four countries, combined with literature study, as documented extensively in D2.1, D3.2 and D4.1.

The **building envelope scenarios** document the (mainly energy-related) characteristics of the building envelope, such as the material composition and presence of insulation in walls, roofs, floors and windows, and the air tightness of the building. The pre-renovation building envelope scenarios mostly consist of uninsulated building components, with the exception of the roofs or floors which in some cases have moderate insulation. The main variation is observed in the windows, where, dependent on the heritage value scenario, either original windows and glazing with low energy performance remain, or windows have already been renovated to a medium energy performance in the late 20th century. The overall building air tightness is rather low. The renovation building envelope scenarios mostly apply common practice renovation solutions with contemporary energy performance to the elements with limited heritage restrictions, while elements with higher heritage value may remain original or undergo low energy performance common practice renovations.

The **space conditioning scenarios** describe the heating and cooling emission and distribution system, the ventilation systems and their controls. The pre-renovation space conditioning scenarios either have central heating systems (typically with radiators and operated with room or central thermostats) or still use local heating elements (mostly wood stoves, or electric elements) as in the original buildings usually local heating was applied. In none of the archetypes cooling is applied. In general, no ventilation systems are applied, so the building is mostly ventilated via manual operation of the windows, stack effect and air leakage. In the renovation baseline, the original heat emission systems are mostly maintained. In the Italian archetypes a cooling system is added. In the Estonian and Belgian cases mechanical ventilation systems with heat recovery are installed, and in the Norwegian case mechanical extraction ventilation is applied.

The **energy system scenarios** document the key characteristics of the building energy generation and storage, including systems serving heating, cooling and domestic hot water to the building, the energy storage components and solar energy systems. In the pre-renovation baselines heat is typically provided via central or decentral gas or electric boilers, and/or via local wood stoves. In the renovation baseline, central or decentral gas or electric boilers are still used, but usually more recent higher performance types. In Italy, connection to the district heating grid is also a renovation scenario. Also, in the Italian case, cooling is provided using an air-to-air heat pump. Solar energy systems are mostly not applied, apart from a limited amount of PV installed in the Belgian cases.

7.2. Perspectives

The baseline scenarios for the main archetypes will be modelled using multi-zone building energy simulation (BES) models, verified by means of IEQ and/or energy measurements in the case study buildings (see D3.2), and assessed using the project KPI (see D5.5), in the "Baseline BES-models" report D3.3.

While the baseline scenarios are documented in this report, the state-of-the-art and innovative solutions applied in the HeriTACE renovation approach for the various building components are documented in D2.2 (building envelope solutions), D3.1 (space conditioning solutions) and D4.1 (energy system solutions). Optimised combinations of these solutions will be assembled into the HeriTACE renovation scenarios, as the HeriTACE research and development, design and modelling tasks are proceeding. They will be modelled and assessed and compared to the baseline scenarios in the D3.8, D3.9, D4.7 and D4.9.

Finally, the baseline scenarios are also the reference point for assessments in the multi-dimensional model for holistic and multi-scale assessment of heritage buildings, that is developed in WP5 and reported in D5.7 and D5.8.

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D2.1 Building envelope characteristics.

D2.2 Energy conservation measures inventory. https://zenodo.org/records/15364987

D3.1 HVAC concepts for heritage buildings. https://zenodo.org/records/15365094

D3.2 Comfort and IAQ in heritage townhouses.

D4.1 R²ES-based energy supply concepts for heritage buildings in historical neighbourhoods.

D5.1 Case-study selection at building and neighbourhood levels. https://zenodo.org/records/15365504

D5.2 Cultural heritage analysis and value assessment.

D5.3 Cultural heritage building user and owner perspectives.

D5.4 Baseline scenarios

D5.5 Map of KPI

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