4RinEU

Reliable models for deep renovation

D4.3

WP4

Report describing the case of historic building

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Foreword

Despite the low energy performances of the European building stock, the yearly renovation rate and the choice to perform a building deep renovation is strongly affected by uncertainties in terms of costs and benefits in the life cycle.

The project 4RinEU faces these challenges, offering technology solutions and strategies to encourage the existing building stock transformation, fostering the use of renewable energies, and providing reliable business models to support a deep renovation.

4RinEU project minimizes failures in design and implementation, manages different stages of the deep renovation process - from the preliminary audit up to the end-of-life - and provides information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is based on 3 pillars:

- *technologies* - driven by robustness - to decrease net primary energy use (60 to 70% compared to pre-renovation), allowing a reduction of life cycle costs over 30 years (15% compared to a typical renovation);
- *methodologies* - driven by usability - to support the design and implementation of the technologies, encouraging all stakeholders' involvement and ensuring the reduction of the renovation time;
- *business models* - driven by reliability - to enhance the level of confidence of deep renovation investors, increasing the EU building stock transformation rate.

4RinEU technologies, tools and procedures are expected to generate significant impacts: energy savings, reduction of renovation time, improvement of occupants IEQ conditions, optimization of RES use, acceleration of EU residential building renovation rate. This will bring a revitalization of the EU construction sectors, making renovation easier, quicker and more sustainable.

4RinEU is a project funded by the European Commission under the Horizon 2020 Programme and runs for four years from 2016 to 2020.

The 4RinEU consortium is pleased to present this report which is one of the public deliverables from the project work.

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Executive Summary

The report describes the results of Task 4.3 - *The case of historic buildings*. The presentation begins with general considerations on the topic of Energy Efficiency and Historic Buildings. It explains what is meant by historic buildings and which important statements and guidelines at the international level provide orientation for the sustainable treatment of historic assets.

We cannot exclude historical buildings from our efforts to achieve climate goals. Historic buildings constitute a considerable share of the building stock in many countries around the world. As many as 25% of the existing residential buildings in Europe were built before 1945. The average energy consumption in historic buildings is considerably higher than in modern buildings. It is estimated that the retrofit of European dwelling stock built before 1945 could save up to 180 Mt of CO_2 within 2050. But when they are renovated, special attention must be paid to preserving their historical and architectural values. Moreover, standard solutions are considered generally inapplicable because the historical stock is largely inhomogeneous. However, with the classification of the historic building stock, an attempt is being made to offer indications for adequate solutions. Based on the experiences of past and ongoing research projects (FP7 3Encult, FP7 EFFESSUS, IEA-SHC Task 59) as well as on the guidelines of the heritage experts in the different countries, renovation objectives for the historic stock is considered in the context of 4RinEU technologies. It was necessary to investigate whether there are groups of historic buildings that are suitable for the implementation of 4RinEU technologies. The parameters for such a clustering were set based on different approaches from previous research projects and in accordance with the archetype definition within 4RinEU. To get an insight into the existing historic building stock in Europe, the clustering was examined in more detail for two countries, Norway and Spain, representing their geo-clusters.

On the other hand, a heritage impact assessment for the 4RinEU technologies is being investigated. This can help for evaluating the applicability in a specific case, as a final decision on adequate solutions for the historic building stock must always be made on a case-by-case basis. There are various approaches to reconciling and balancing historical and energetic aspects in a decision process. The report will explain an approach, for the viability of 4RinEU renovation packages balancing energy and heritage values.

Based on these preliminary considerations, to what extent the Cost-effectiveness rating system (Result 10) developed in 4RinEU could also be used for historic buildings had to be examined, or in which form it would have to be extended accordingly. Although heritage-relevant KPIs and special risk management for historic buildings are possible to include in the tool, the conclusion remains that the benefit of such an expansion is doubtful.

For the 3 historic building demo-cases in Norway, Netherlands, and Ireland, belonging to three different Geo-clusters, the application of the 4RinEU technologies is tested and the

transferability of the results examined. For this purpose, the buildings are first characterised with their archetypes in terms of building typologies, structural elements, energy consumption, heritage significance, and others. This includes also specific renovation needs and existing recommendations for energy renovations in the respective context. The central topic is the question of whether historic buildings could be suitable for the application of a prefabricated façade in a specific case. Although possibilities exist in individual cases and are also shown here, it remains to be concluded that these are mainly exceptions. Regarding the replication potential of these exceptions a broad applicability cannot be assumed, which is why the advantages of such prefabrication - such as cost-effectiveness, robustness and shortening of the construction site time - only have a very limited effect in historic buildings.

1 Introduction

1.1 Method and integration into the 4RinEU activities

The report Deliverable 4.3 presents the results of the activities carried out under *Task 4.3 - The case of historic buildings*. The main objective of the task was to evaluate the applicability of 4RinEU technologies and renovation packages for the historic building stock and assess the related replication potential. For this purpose, in the project proposal, it was planned to:

- Define renovation objectives for historic buildings starting from EURAC experience as developed in FP7 3ENCult project.
- Identify possible cases of listed and not listed historic building in EU building stock and analysis of viability for 4RinEU renovation packages, studying, in particular, the possible monetization of architectonic value conservation, and possible ERDF or local funding schemes, considering the historic buildings as a common good and crucial element for the urban valorization of city centres.
- Define together with the 4RinEU case studies owners possible action for historic buildings in the demo-case owners' building stock, in connection with T4.4 and T4.6.

The results of the study should feed into 4RinEU Result10, what is the Cost Effectiveness Rating Tool.

Task 4.3 with the focus on historic buildings contributes with a new aspect to the 4RinEU project. All technologies and methods in the project were developed independently from the special requirements of the historic building stock. Anyhow, it was the aim to assess their applicability also for this group of buildings. Since it did not seem reasonable to include all historic buildings in these considerations, a definition was first made of the existing buildings to be considered. Furthermore, the energy renovation principles for historic buildings in Europe were examined. This was also done for the purpose of informing about common practices in dealing with the historic building stock. Special attention was paid to the different methods for determining historical values, which are then included in a balancing process of heritage conservation and energy efficiency aspects.

In the next step, possible case studies of historic buildings were identified which should serve for the analysis of the viability of the 4RinEU renovation packages. Following the geo-cluster approach by 4RinEU these historic building case studies were supposed to represent appropriate Archetypes in three different geo-cluster. Since it was originally planned to carry out the considerations about the historic buildings on examples in the 4RinEU demo case countries, the analysis of the historic building stock was started for Norway, Spain and the Netherlands.

There exist different approaches in the categorization of historic buildings into archetypes, bottom-up as well as top-down. To identify the best way for the activities in 4RinEU, these different approaches were assessed according to their suitability. Based on this analysis, the building stock in Norway and Spain was clustered in building typologies.

With the 4RinEU project activities, it was also planned to use the developed technologies not only in practical demo cases but also to investigate their possible application in so-called Early Adopters. One of these Early Adopters selected during the project was the Chamber of Commerce in Limerick/Ireland - a historic listed building. It was then decided to include this building as one of the historical case studies in Task 4.3, in exchange for the planned case study in Spain.

For all three selected historical case studies, the corresponding archetypes to which they belong were finally defined. This was necessary to evaluate the considerations regarding the applicability of 4RinEU solutions in terms of their transferability potential. Another benefit was to examine the inclusion of historic building typologies in the rating tool developed under WP4 (Result 10). For this purpose, it was first worked out which basic extensions of the tool would be necessary to be able to apply it to historic buildings as well. In the individual analysis of the historic case studies, the single components of the 4RinEU solution packages were examined qualitatively to see whether and under which conditions they could be applied.

1.2 Definitions of terms and object of consideration

Historic buildings are trademarks of the European building stock. Nevertheless, they are held responsible for a great share of GHG emissions. However, if one takes a closer look, the term "historic building" is defined quite differently. A few introductory considerations should therefore be made to clarify the term so that the following explanations can be properly classified.

The term "historic/historical" building stock is understood very differently in different surveys and projects. In general, the end of the Second World War (WW2) in 1945 is mostly regarded as a border mark in research projects, and all buildings erected before WW2 are described as historic.[1] The EFFESUS project has shown that the national age classes vary, it considers that the border ranges between 1945 and 1950 [2]. This amounts to a huge number of buildings. All these buildings regarded as historic are however not necessarily under legal protection, and therefore assets of heritage preservation. Furthermore, heritage preservation seeks to protect buildings, objects, and landscapes of historical significance, not necessarily erected before 1945.

> *"Whereas the quantum of Europe's historic building stock which has officially been designated as heritage amounts to less than 3 per cent of the total, the extent of the pre-1945 stock is revealed in Dol and Haffner (2010) as representing 23 per cent" [3]*

Although there is a difference between the structure of the building stock in Europe and the work of heritage preservation in the individual countries, some definitions are given below of how the building classifications are to be understood in the following report.

Historic Buildings: In 4RinEU all buildings are considered as "historic buildings" with certain historical significance including all buildings erected before 1945 (having their significance at least because of the age of the structure) and additionally buildings erected after 1945 considered as cultural heritage by national heritage authorities or even these considered worthy of protection. This is a broad, inhomogeneous building group.

Vernacular/Traditional Architecture: Vernacular/traditional architecture is considered as what was usually erected before the standardization of materials and design commenced (with/following the industrial revolution usually) and is therefore strongly influenced by its environment. It follows local building techniques and was built with locally available materials. Traditional architecture is therefore often very typical of geographically limited regions and was often realized even after the Industrial Revolution, despite the fact that more modern construction methods and materials were already introduced. Traditional architecture can be less divided along national borders. Building types rather include areas with similar geographical and climatic conditions, in addition to being characterized using similar building materials.

Vernacular "Architecture takes maximum advantage of the environment's possibilities with the optimal economy of means. Building materials are taken near the construction site. The material and the construction technique determine the architecture. However, it is proven that the combination of the different natural and human characteristics of the environment has determined the constructive, formal and functional traditions, e.g. there are stone architecture if there is stone in the place and the inhabitants know the work of stone-cut."[4]

Due to the great overlap between vernacular architecture and historic buildings, many of the following statements for the building stock can also be applied to vernacular architecture.

Historic Urban District: In this report, we follow the definition of EFFESUS: "a significant grouping of old buildings, built before 1945 and representative of the period of their construction or history", and comprising "buildings which are not necessarily protected by heritage legislation". In the 4RinEU project, the restriction to pre-1945 buildings was eliminated and extended by districts erected after 1945, usually housing estates, with dedicated architectural value.

Listed Buildings: By this, we mean all buildings and other historical structures protected by the respective national law. As a rule, the buildings are registered in lists, which are kept by the responsible heritage authorities, or clear guidelines formulated for the legal protection of the buildings (e.g. all buildings erected before 1700). Listing emphasizes the certain architectural and historic interest or value, and opens for considerations within the planning system, to achieve protection also for future generations. In some of the EU states, a classification of the listed monuments according to their importance is carried out, for instance of buildings of national interest, regional interest, local interest, and not listed buildings eligible for protection.

2 Historic buildings and Energy Efficiency in Europe

The building sector in the European Union consumes almost 40% of the total energy consumption and is responsible for 36% of CO_2 emissions. Therefore, the building sector has a significant energy efficiency potential. Most of the existing buildings have high energy consumptions and significantly lower thermal properties than achievable by currently available technologies.

"*The carbon saving potential associated with the energy retrofit of existing buildings is well known. Historic buildings account for a large fraction of the residential built stock in many countries around the world. In the UK, Spain, Denmark, and France, more than 20 percent of the existing buildings were built before 1919 and almost 40 percent before 1945. Their refurbishment could avoid the emission of up to 180 Mt of carbon dioxide (CO2). Beyond the opportunity for energy and carbon savings, the built heritage needs continuous care and maintenance to sustain* *their functionality and avoid decay. As stated by the International Council on Monuments & Sites (ICOMOS) in their Charter on the built vernacular heritage, […]. Improving the energy performance of these buildings will also improve the internal comfort conditions. Providing users with current standards of comfort is a crucial requirement to ensure the continued use of historic buildings over time and with that their conservation and durability." [5]*

Cultural heritage, and historic buildings in general, cannot be defined by physical characteristics alone. Cultural values are assigned to these buildings, making them an anchor point of identity creation. Ambitious energy efficiency measures may also lead to damages and/or decrease the socio-cultural value, due to the use of materials that do not fit (chemically or mechanically) with the original materials, or that covers the original yet vulnerable facades etc. Thus, the impact of upgrading/retrofitting may be fatal for the cultural/historic/architectural value of the building if not carried out properly. The significance of the monuments, however, remains bound to their material substance, so that preserving the buildings with all their assigned values remains a task for all public and private owners and the whole society.

There is a set of international declarations dedicated to the definition of cultural heritage, among others:

- **Convention on the Value of Cultural Heritage for Society (Faro Convention, 2005)** The Faro Convention emphasizes the important aspects of heritage as they relate to human rights and democracy. It promotes a wider understanding of heritage and its relationship to communities and society;
- **The Krakow Charter, ICOMOS, 2000** Referring to the Charter of Venice, the Krakow Charter states the plurality of heritage;
- **The Nara Document on Authenticity, ICOMOS, 1994** Using a different concept and value of time and heritage, the Nara Document broadens the definition of authenticity of cultural properties;
- **World Heritage Convention, UNESCO 1972** The World Heritage Convention 1972 links the concept of nature conservation and the preservation of cultural properties in a single document;
- **The Venice Charter, ICOMOS 1964** The Venice Charter for the Conservation and Restoration of Monuments and Sites is the original and most important source of principles guiding to the preservation and restoration of historic buildings. It is a rich definition of cultural heritage that pays special attention to the concept of authenticity.

In the meantime, there is a whole range of documents and scientific publications that deal specifically with the topic of energy efficiency in historic buildings. European research projects such as 3ENCULT, EFFESUS, RIBuild and PRO-Heritage have been specifically funded under this focus and have developed guidelines for dealing with historic building structures in the context of energy-efficient renovation. [3,6] The IEA-SHC Task 59 is a collaborative research project of the International Energy Agency with the focus on the preservation of historic buildings.

On European level the CEN standard EN 16883 "Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings" was established in January 2017. The guidelines are not limited to listed buildings with formal protection. Rather than specifying general solutions beforehand, this standard provides a procedure to facilitate the best decision for each individual building.

2.1 Historic building stock in Europe

Even with the establishment of the 1945 border mark, there are different indications of the historic building stock. The EU project EFFESUS assumes a percentage share of 23.1% in the number of dwellings from before 1945 (EU 28, Norway, Switzerland and Turkey) [2], the evaluation of the statistic of the Census 2011 results in a share of about 20% (Figure 1).

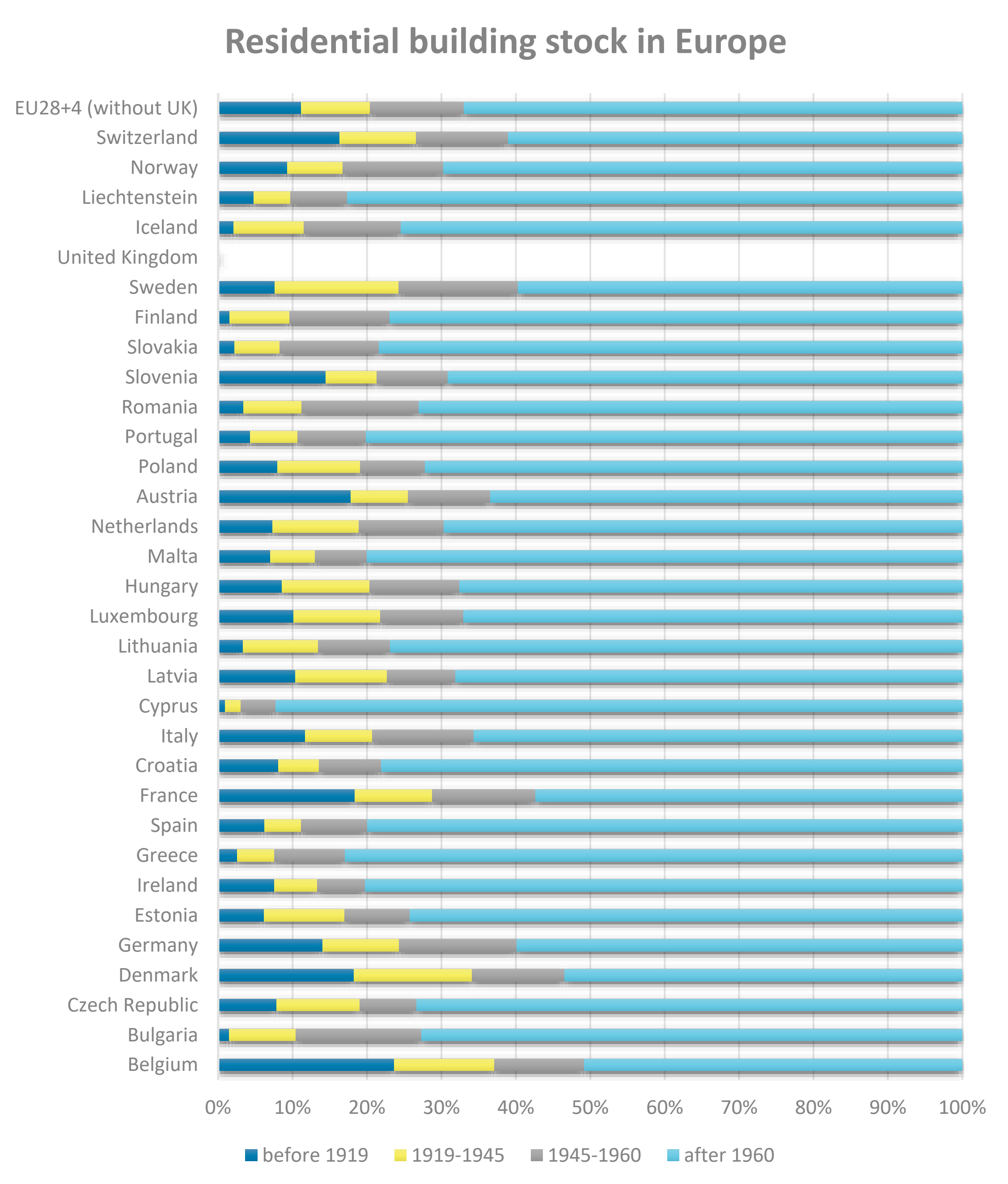


Figure 1 Dwellings by period of construction, national averages, 2011. Source: of data: Eurostat (Census hub HC53), data extracted on 28-09-2017.

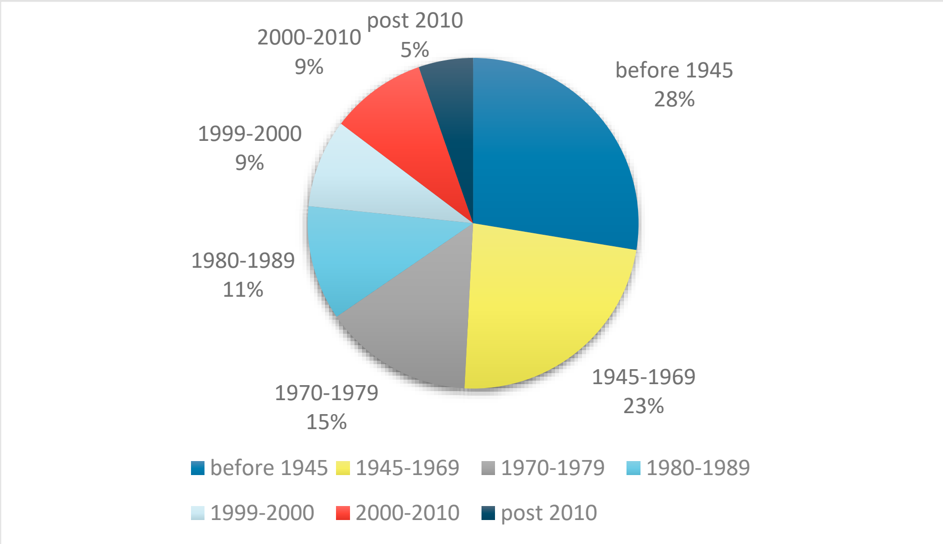


Figure 2 Space Heating and domestic hot water demand in the residential sector. Source: Simon Pezzutto et all: HOTMAPS, D2.3 WP2 Report –Open Data Set for the EU28.

Data collected during the EU HORIZON 2020 HOTMAPS project indicates the total energy consumption for the residential sector and the share of residential buildings erected before 1945 accounts to be 28% or more than a quarter of the total consumption. (Figure 2) This is reason enough to develop specially adapted solutions for the historic building stock, which in turn will both reduce energy consumption and protect existing cultural values.

The following Table 1 is taken from the study "European Buildings under the microscope" 2015. It shows the calculated total energy consumption of residential buildings related to building age and geographic location. [7]

Table 1 Regulated final energy for residential properties (GWh per annum), Source: Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings. Published by Buildings Performance Institute Europe, Editor: Marina Economidou, October 2011.

Regulated Energy (GWh)		North & West	South	Central & East	Total
Old	Pre 1960	1 193 504	228 933	183 937	1 606 374
Modern	1961-1990	506 461	198 250	266 647	971 358
Recent	1991-2010	136 319	41 581	52 551	230 452
New	2011-2020	28 390	11 718	11 394	51 501

For Northern, Western, and Southern Europe the values of total Energy demand for the historic building stock is as expected. Here, the older buildings erected before 1960 have the highest total energy demand. In Central and Eastern Europe, on the other hand, the final energy demand for buildings is clearly higher for buildings from 1961-1990. This may in particular be related to the high amount of the newly constructed buildings in the corresponding age band.

The following takes a closer look at the historic building stock of Netherlands and Norway as representatives of the geo-clusters Continental-Central and Northern.

Historic building stock in the Netherlands

For the Netherlands, Van Kugten et all (2016) emphasize in their report that dwellings built during the post-war period, 1945-1970, account for more than one-fourth of the housing stock in the Netherlands. It is assumed that historical dwellings in post-war neighbourhoods are less energy-efficient and less transformed compared to other historical dwellings. This high percentage of post-war dwellings is also emphasized in the paper for Germany (46 percent), Italy, and Romania (37 percent). Post-war dwellings are often characterized by poor energy performance (Agricola et al., 1997). Buildings built between 1941 and 1960 have the highest U-value (thermal transmittance, W/(m² K)), meaning they have the lowest thermal resistance, compared to all other building periods (BPIE, 2011) [8]. This fact is also illustrated in the graph in Figure 3, where the share of energy efficiency labels is shown - separated into historical post-war buildings and newer constructions.

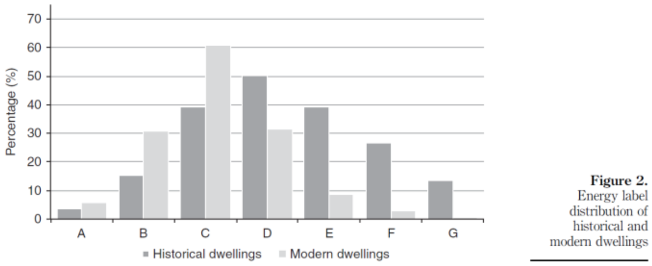


Figure 3 Energy label distribution of unlisted historical dwellings (Historical = post-war dwellings in that case) (figure from Van Krugten et al 2016)

In the Netherlands, the monument law also protects listed dwellings (Monumentenwet, 2015). Listed dwellings can be distinguished into national heritage, which are designated by the national government and municipal heritage, which are designated by the municipality (Monumenten.nl, 2015). [8]

Historic building stock in Norway – (Geo-cluster Northern)

Another case study in this research is located in Norway. In 2009, SINTEF prepared a comprehensive Energy analysis of Norwegian Building Stock within the scope of the IEA Task 37: Advanced Housing Renovation by Solar and Conservation. (Thyholt et all 2009) The report maintains that most of the Norwegian Dwelling stock (i.e. about 90 %) was built after the Second World War [9]. Another source, the UNECE-report considers the percentage of dwellings in the CENSUS categories for age distribution. [10] There, the amount of dwellings in Norway built before 1945 results in about 20%. However, it remains to be emphasised that the share of historic buildings in Norway is lower than the overall share in the European 28 countries.

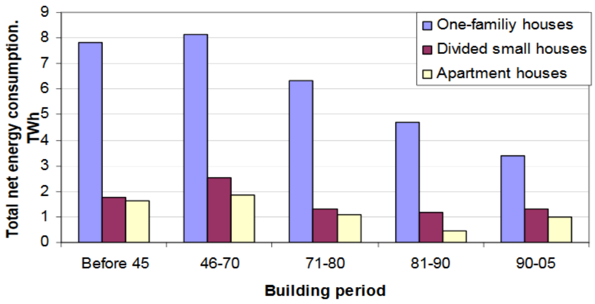


Figure 4 Total heated area split into the three categories of dwellings, according to building age. Source: Thyholt et all (2009).

Regarding the age distribution of the residential building stock relative to the square meters, buildings built between 1945 and 1970 represent a larger proportion than those before 1945.
However, the construction of single-family houses in Norway is the main component of the historical housing stock, both by number of dwellings and by square meters. The SINTEF report (Thyholt et all 2009) also elaborates on

the different heating systems in use, without finding any significant differences to the younger building stock. This is explained by systems upgrading in many cases.

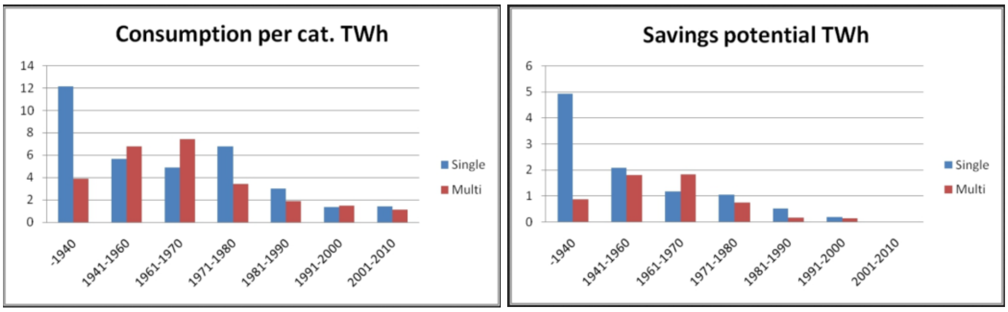


Figure 5 Energy consumption for heating and warm water by year of construction (left), and Calculated savings potential by year of construction (right). Source: vmisenergy 2012, there Fig. 2 and 3.

In comparison, an analysis of the Swedish building stock - also part of the Northern Geo-Cluster – correspondingly shows an increased need for action in the sector of historic single-family houses. Due to the high proportion of single-family homes, these also account for a large share of the annual energy consumption, especially in the older buildings. Consequently, the experts also here see the highest savings potential [11].

Heritage Preservation issues in Norway

The purpose of cultural heritage management in Norway is described in **the Cultural Heritage Act [**12]. Buildings, groups of buildings, and cultural landscapes can be objects of protection. If the properties are dating back to before 1537 (for buildings: before 1650) they are automatically protected, while those dating from 1537/1650 onwards are granted on a case-to-case basis.
The historic buildings in the municipality Oslo, the Cultural Heritage Management Office has developed a categorization system for historic buildings. It divides listed buildings into three categories; red, yellow and orange. Red is protected (considered to be of national value), orange is protected according to the Norwegian planning and building act, and yellow covers buildings considered to be worthy of protection. The different categories are drawn from different legal documents. This is explained in the document «informasjon om gul liste» (https://byantikvaren.no/gul-liste/).

2.2 Building archetypes, building categorization and sample buildings

The relevance for the renovation of historic buildings was presented in the previous chapter. To enable a statement that is as generally valid as possible, a systematic overview of the building types employed in the investigation is presented. For this purpose, the historic building stock of the individual demonstration countries was first clustered. The approaches in such categorization are highly different, some of which differ fundamentally from the typology of the more recent building stock. The reason for this is the great heterogeneity of the historical building stock. Buildings that could be included in the same building class according to age and size, can be very different, as illustrated by the examples in Figure 6.

	
Villa Schapira as seen from Türkenschanzpark entrance, ©Michael Hilgers *The Villa Schapira was built in 1922 in the 'baroqueising Heimatstil'.*	*Villa Kluge at Rupenhorn, Berlin* *Architectural partnership Hans and Wassili Luckardt and Alfons Anker, Completed in 1928* *Steel framework building in the New Building style*

Figure 6 Different characteristics of two Villas from nearly the same building period in Germany.

Due to the heterogeneity of the historic building stock, a comprehensive analysis of the old buildings is necessary for the development of tailored solutions. A complex building stock can be described by archetypes or sample buildings.

The detection and description of existing buildings by sample buildings for which data are obtained through measurement (top-down approach), should be distinguished from the bottom-up approach of the archetype formation. A thermal characterization of the building stock can be carried out by implying extensive samples and the quantifying of parameters describing the thermal performance. The approach, and finally the definition of archetypes or building categories, always depends on the purpose of the study. Some approaches of the building cluster are presented in the following. Purposely, the examples refer to approaches that include the historic building stock in their considerations.

2.2.1 The European Building Stock through archetypes (Chalmers)[13]

To describe a building stock by archetype buildings, Josep Maria Ribas Portella (2012) describes in her Master thesis a bottom-up approach consisting of 1) segmentation, 2) characterization, 3) quantification and 4) validation, which is presented in Figure 7. [14]

By using the so-called ECCABS model for energy simulation, data on net and final energy demand for the entire sector can be provided. ECCABS stands for Energy, Carbon and Cost Assessment for Building Stocks. Calculations done with the parameter defined for the archetype buildings can be used in a top-down approach to estimate the consumption of a whole building stock.[15]. Due to the flexibility of the detail level, the model is also applicable for the historic building stock.

In the study, the building stock in France, Germany, Spain, and the UK was considered since it counts for approximately half of the total energy consumption of EU-27 (the 27 European Union countries after the UK left the EU) buildings. Data was compiled through several surveys conducted on a country basis, for which corresponding reports were available. The segmentation criteria were selected according to the impact on energy demand and available data sources in national reports. The criteria include building type, construction year, heating system, and climate zone. While the approach is certainly interesting for the overall building stock, only limited information can be drawn from the study for the historic buildings, as buildings before 1975 were summarized in only one age-category.

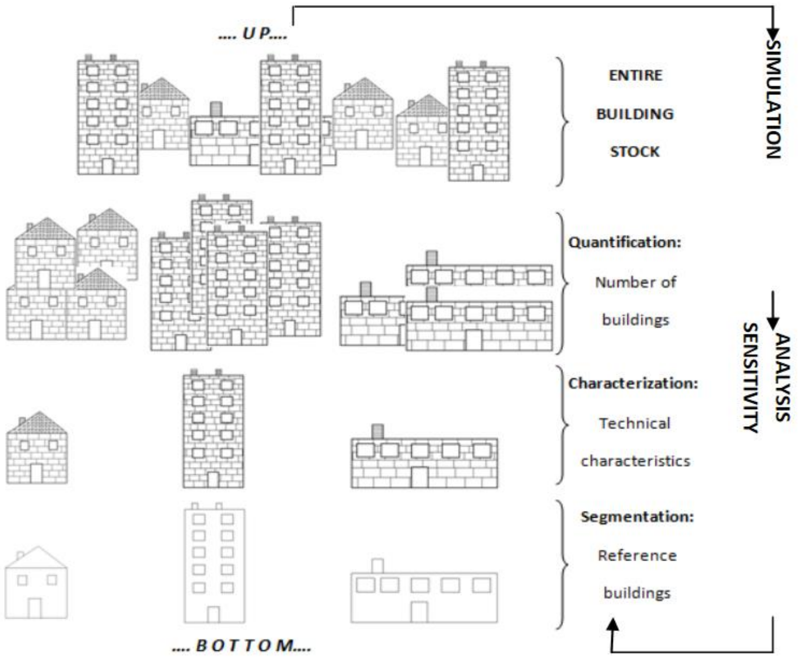


Figure 7 Methodology based on a bottom-up approach to describe the building stock through archetype buildings, used in the master thesis "Bottom-up description of the French building stock, including archetype buildings and energy demand" by JOSEP MARIA RIBAS PORTELLA [Portella 2012]

TABULA Typologies

The TABULA project structures the existing building stock according to typologies in terms of energy-related features. The term "building typology" in this case refers to a "systematic describing of the criteria for the definition of typical buildings as well as to the set of building types itself" [16]. A common approach of building typologies was developed, with a classification system, a structure for building and supply system data, and a coherent energy balance method. The TABULA approach allows the development of a comparable national or regional building typology. In the typology approach, a dependency is assumed, of the elements in the thermal envelope (i.e., roof, top ceiling, wall, windows, and floor) on the building size and the construction time. The overall objective is placed on the energy consumption for space heating and hot water, according to several parameters. Among these parameters are the construction year, building size and neighbour situation, the type and age of the supply system, and the question of already implemented energy saving/efficiency measures. The TABULA classification is a kind of building physics-based modelling. Although the tabula approach is certainly one of the most important sources for a typology of the building stock in Europe, it does not do justice to the diversity of the historical building stock.

JRC Report

The report on "Environmental improvement potential of residential buildings" was a scientific contribution of the JRC to the European Commission's Integrated Product Policy framework which seeks to minimize the environmental degradation caused by the life cycle of products.
Unlike other categorization methods, the report however defines typical constructions that occur over several time periods as well as across countries. Thus, the age bands are not primary categorization aspects, thus used mainly to simplify the overview. The report assumes three age categories as the highest aggregated level for each country:

- until 1945 (old buildings);

- between 1946 until 1990 (post-war buildings);
- after 1991 (current and new buildings).

Through the analysis of the building stock according to building typologies and independent from age classes, it was an aim to demonstrate not only the influence of factors like population and economic growth but also the impacts of national housing and funding policies.

In the JRC report, the construction types were not sharply delimited chronologically and overlapping building age classes were introduced. These age bands also differ between the countries. Where necessary, additional building types were created in case different materials and structures of the façade or different roof and floor constructions were assessed for one selected national group of buildings at a certain age and size. For instance, flat and pitched roofs, with their different constructions, were to be split into two groups[17]. The result is a detailed description of the constructions, covering used material and masses as shown in table 3.6 below with an example from a multi-family house in France.

Table 2 Example of a defined construction type according to Table 3.6 of the JRC report: Material and masses for a typical multi-family house in France (between 1945 and 1990, Multi-family house Brick masonry, reinforced concrete flooring, pitched roof 20°)

Year of construction	1945 – 1990
Building type	Multi-family house
Dimension	32 m x 12 m
Floor to floor height	3 m
Roof	Pitched roof 20°
Roof cladding	Brick
External wall	Brick masonry 30 cm
Interior load-bearing wall	Reinforced concrete 20 cm
Interior wall	Plasterboard 10 cm
Plaster	Exterior plaster: lime-cement; interior plaster: lime-gypsum
Floor	Reinforced concrete 20 cm
Basement wall	Reinforced concrete 20 cm
Basement ceiling	Reinforced concrete
Foundation	Reinforced concrete
Window	Wooden frame and double-glazing

Figure 8 Example of Panel buildings in the JRC report: Figure 3.3 Panel buildings especially erected in the eastern European states, Source: [WETZEL &VOGDT 2005]. In the EU-25, altogether 34 million dwellings or 17% of the whole buildings stock are included in panel buildings. In each country where these buildings exist, one to three different building types were defined

To avoid that the number of the defined construction types/categories became too comprehensive, special or atypical construction types only present in a small number, have been omitted in the analysis. Besides the materials and dimensions, also the reference service life of the different construction elements and the use phase of the building types were analyzed. The target was a 70% coverage of the building stock with the defined types for each country and whole of EU countries. In this way, 53 typical construction types were developed for the existing European residential building sector.
"Of these 53 building types, 19 types were each subdivided into one group representing the existing building stock, and one group representing the current typical practice of residential building construction (new buildings), respectively. Thus, in total 72 building types were identified that altogether represent 80% of the whole building stock in the EU-25 in terms of residential area" [18].

EFFESUS categorization

Also, the EU FP7 EFFESUS project started with a building stock modelling and categorization job, with certain regards to historic districts. A comprehensive literature review identified a lack of methodologies tailored to historic buildings, including parameters like heritage protection and cultural values. A method was developed on the definition of the data structure (the required information) and the categorization (the processing of information).

A minimum of required data for data acquisition was defined:

- Building identification;
- Year of main construction;
- Building geometry;
- Nr. of adjoining walls;
- Exterior envelope;
- Type of construction (from predefined list);
- Operation/use;
- Predominant energy supply and distributing system;
- Assessment of cultural heritage significance, specific legal protection.

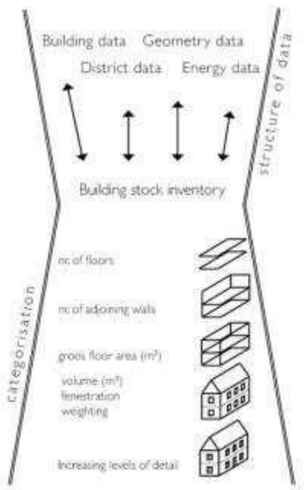


Figure 9 A schematic flowchart shows how the required input defines the possible output, and vice versa. Source: EFFESUS report D 1.4.

Buildings were described in five levels of detail in a CityGML data model, extended by additional increasing levels of detail (heating systems, cultural heritage values, construction material). This resulted in a typological tree structure, with a limited number of physical categories that can be modelled for energy calculations. Each physical category was divided into subcategories according to heating systems, impact indicators, and others, and facilitated the analysis of many subcategories, using the same physical model.[19]

The SusCity project, Portugal [20]

Monteiroa et all (2016) describe in the paper related to the SusCity project a new methodology for building stock classification applicable at different detail levels based on a multi-detail archetype classification. The aim was to develop a methodology to serve as a basis for urban energy modelling. In the study of the SusCity project, the impact of different detail levels in the characterization of the building stock on the accuracy of performed energy studies was assessed. A neighbourhood in Lisbon was chosen as a case study. The findings suggest that an "oversimplification might lead to large differences, there is also no need to consider a very detailed characterization of the building stock to obtained consistent results." Generally, a correlation between the number of archetypes and model accuracy was determined. It seems evident that the higher the diversity of the building stock, the more archetypes are needed to represent it. At this, historically developed cities and neighbourhoods require more detailed analyses compared to urban districts with uniform building structures planned and realized as a whole.

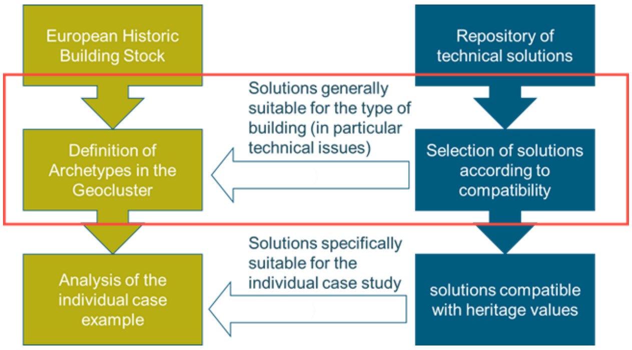
EU project GEO4CIVHIC

The aim of the GEO4CIVHIC study, described in De Carli et. all (2019) [21], was to form proper building archetypes according to the European building stock in an urban context, in order to apply geothermal energy in city centres. In this context, they considered archetypes as buildings that may occur more frequently in urban environments around Europe. Out of 3 defined groups, reference buildings applying to three different climate conditions related to different energy demand and building constructions were chosen. Also, a differentiation between historic buildings (before 1660) and more recent buildings was employed. In the study, "historical buildings" were considered to be opening for only partial retrofit projects. These archetypes have to be examined in terms of geometry, thermal properties of the envelope, type of use, and type of HVAC installed. For the description of the individual parameter, De Carli et. all again refer to the TABULA-EPISCOPE definitions.

2.2.2 4RinEU Historic Building Archetypes

The typology approach in 4RinEU focuses on the consideration of sample buildings. A building typology of the total building stock based on the results presented in the JRC report form the basis for the selection of the sample buildings. In the Tabula project, an aim was to harmonize national typology approaches in Europe, with the purpose of comparability. Here, the individual development of the architecture is also considered. This seems to be necessary, due to the need of adapting technical solutions and business models to individual building types, which can be quite different despite the same construction period. In addition, the climate conditions may vary greatly even within one country, which is an important variable to consider. In this way, the comparability of the individual countries considered is no longer directly given, and a more individual approach with adaptation of refurbishment measures is made possible.
The building archetypes in 4RinEU were defined for the reference countries in each Geo-cluster (see. Deliverable 2.1). For each Geo-cluster, four representative archetypes were selected according to the statistical aspects. The archetypes were based on the national building typologies in the Tabula project. While this approach is appropriate to provide input on technical data for simulation and parametrization, it does not cover the diversity of the historic building stock. Nevertheless, some of the defined archetypes are also covering parts of historic or protected buildings. They can be employed for considering thermal performance even if further aspects must be considered when dealing with historic or listed buildings. However, as historic buildings are considered to induce a large share of energy consumption, this group of buildings should not be excluded per se from the considerations in 4RinEU. An important factor is however that the renovation rates are below the targeted goals. The definition was therefore

explicitly not made to enable offering a standard solution for the respective building type, but rather to define building clusters where different technologies can be considered. Ultimately, a final decision about the renovation solutions can only be made for the individual case.

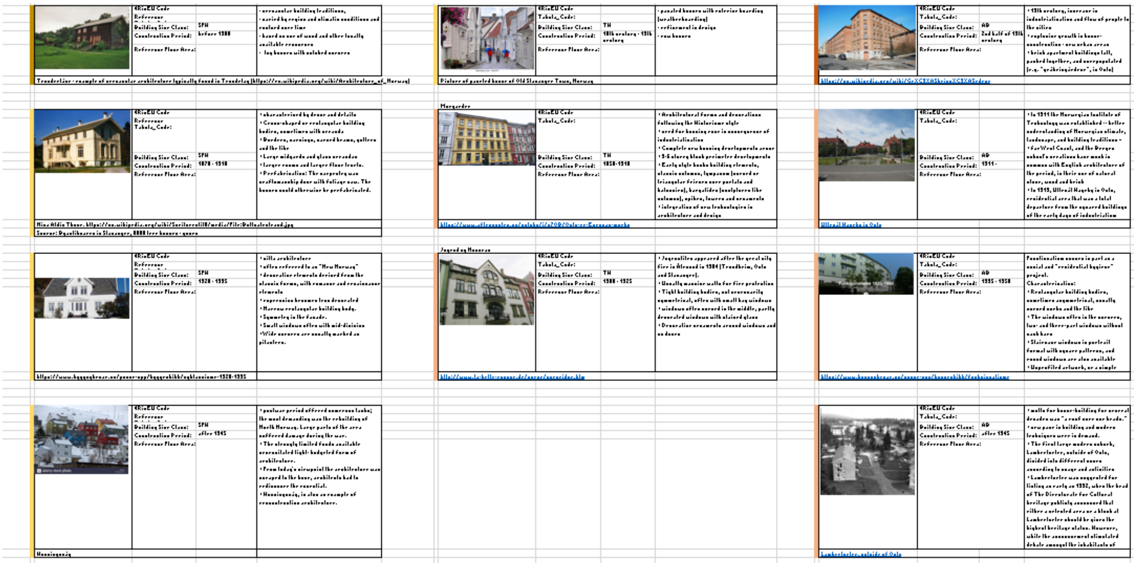


Based on the literature, existing research projects, and national statistics, exemplary historic buildings were clustered in typologies for the countries Norway and Spain. The way of definition follows the approach in the JRC report - i.e. geographical distribution and age range were determined for groups of buildings that belong together according to physical aspects. This is the reason why this type of segmentation does not clearly define age groups.

Historic Building archetypes in Norway

As previously stated, a characterization of the historic building stock based solely on size and building age is not adequate for the inhomogeneous historic building stock. Without claiming to include all historic structures, it was the aim to define clusters that cover as large groups of buildings as possible and are not limited to Norway but partly relevant to a wider geographical area. Thereby, an overview of the historical development of housing in Norway by Elisabeth Seip (Manager of the Norwegian Architecture Museum[22]) served as the main base of information about the historic housing in Norway.
The so defined Historic Building Typologies are presented in Table 3 with their basic characteristics. They are grouped in three columns according to the size -small buildings with 1 and 2-family houses, multifamily houses and apartment blocks.

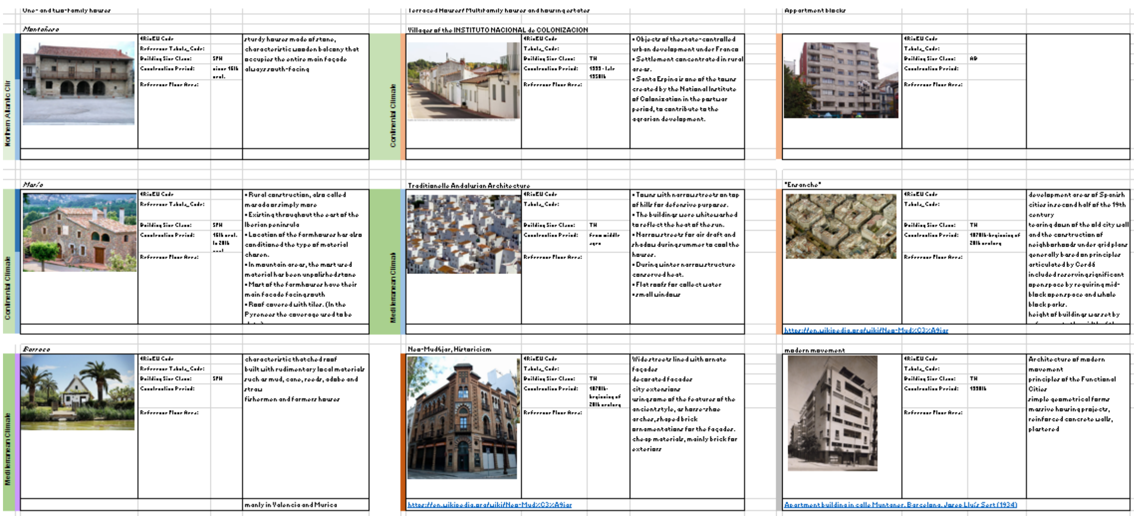
Table 3: 4RinEU Historic Building Typology Norway. The colour code on the left refers to the main building material of the walls. A bigger and better readable table is attached as Annex to this document.



Historic building archetypes Spain

Spain is characterized by an enormous variety of architectural styles and features. A research work from the year 2011 identified 120 archetype buildings corresponding to six building typologies for the Spanish building stock. Five climate zones and four periods of construction are considered [23]. With a focus on the historic building stock, a considerably high variety of archetypes can be identified. In addition to the different climate conditions, the impact of different cultural and political developments is reflected in the different architectural traditions. Also, in TABULA/EPISCOPE three climate zones were considered in the Spanish national building typology definition. The climate zone focus enrichens the typology, yielding a much more detailed picture of the historic building stock than for other countries' typologies in TABULA.
In the 4RinEU project it was therefore neither the aim nor would it have been possible within the limited time and resources to provide a holistic definition of buildings types for the historic Spanish building stock. For all three pillars regarding the size of the buildings, 3 different building types representing a large stock were selected as examples and are presented in the following Table 4.

Table 4 4RinEU Historic Building Typology Spain (Examples). The colour code on the left refers to the main building material of the walls. A bigger and better readable table is attached as Annex to this document.



Historic Building archetypes in Netherlands and Ireland
A segmentation of the historic building stock in the demo countries Ireland and the Netherlands was not performed, as the corresponding case studies to be considered for the historic cases were already predefined. Accordingly, the associated typology was described according to the criteria mentioned above (only for the selected examples).

For the Netherlands, it was decided to refer to the work of Lisanne Havinga, who has worked on post-war-housing neighbourhoods integrating heritage, environmental, and economic impacts in renovation design decisions. Especially after 1950, large scale urbanizations were found together with a network of highways. More than three million houses were built [24] in this period. The post-war architecture was subject to increased recognition as cultural heritage assets, and some buildings were designated as monuments. Further, 14 neighbourhoods are considered as national important, but without an official protection status. The neighbourhoods are on the tentative list of the Cultural Heritage Agency of the Netherlands to be designated as national heritage due to their representative structural plan or building method (Rijksdienst voor het Cultureel Erfgoed, 2011). Regarding the physical conditions, these archetypes correspond to the 4RinEU G3_NL_AB_01. (See Deliverable 2.1 for further explanation).

The Irish case study served as an early adopter case study in the 4RinEU project and was later incorporated into the project work. Because of the historic background of the early adopter case study, it was decided to consider it also in task 4.3 regarding the Historic building case. The chosen case study building is a Victorian-style building, and the architecture is closely linked to the urban character of the neighbourhood. This typology corresponds with the urban extensions of the second half of the 20th century found throughout Europe, mostly developed as perimeter blocks in regular neighbourhoods with inner courtyards.

2.3 Qualitative Analysis of Solutions for historic buildings

2.3.1 Balancing monument values and possible technical solutions

Particularly in connection with energy-efficient refurbishment of historic buildings, questions about the balance between preservation of cultural values and identifying the best technical solutions from an energy perspective arise. Until now, a convincing method has not been presented for a righteous assessment between the qualitative cultural values and the quantitative energetic values, although there have been forwarded suggestions for solutions. The core idea is usually to compile the cultural (heritage) values numerically, in order to provide a direct comparability with e.g. energy saving potentials.

Evaluation of the heritage value in cultural heritage buildings seem to be treated in very different ways throughout the European countries. While in some countries a classification in “high” and “low” heritage value is avoided, other countries work with such a classification in different ways.

A discussion of different evaluation methods of the heritage value in the context of energy retrofit was carried out in the 3ENCULT project. In particular, the concepts of InterSAVE (Denmark) and DuMo –Index (Netherlands) were regarded as possible approaches. The main difference between the two approaches lies in the way the cultural values are assessed. While the InterSAVE concept is a qualitative and quantitative assessment of the cultural value, the Mo-value refers to the changeability index. Both concepts base on the idea of a relation between the historic building category (apart from the method behind the categorization) and the amount of energy-saving options that are possible for the buildings. Of course, what measures are possible differs from case to case.

Figure 10 Illustration of the relation between the historic building category and the amount of energy saving that is possible in the buildings (Note: this is only an example not a fixed correlation) [3Encult D.2.3/3.2]

In general, the triggering of communication among different stakeholder groups and the negotiation space for non-listed (but historic valuable) buildings were seen as the main advantages with the method. On the other hand, the fact that a global rating system is not suitable for individual building characteristics was seen as the main disadvantage.

In the IEA-SHC Task59, the idea of a "Negotiation Space" for the interventions towards the lowest possible energy demand was developed.[25] The approach for the Negotiation space is visualized in Figure 11. Here, the definition of lowest possible energy demand in the context of historic buildings is characterized by the following:

- The idea of a changing negotiation space depending on the building under consideration.
- The negotiation space includes any retrofit measure that is compatible with the building.
- The shaping of the negotiation space always depends on the assessment of the single building.
- The implementation of all compatible measures included in the negotiation space correlates with the lowest possible energy demand.

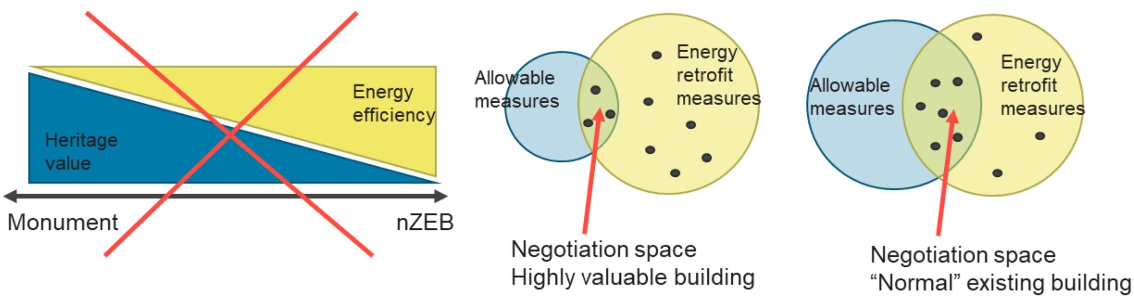


Figure 11 The idea of the negotiation space was developed in IEA-SHC Task 59. Source: Herrera-Avellanosa, et al. 2019

2.3.2 Exploitation in the decision-making process

These procedures are based on the fact that the monument values are assigned to an individual building in each case. Certainly, the methods described are designed to ensure that the attribution takes place according to a fixed system, to allocate the results of the recording into the decision-making process in an "objectified" form.

For regionally limited areas, such rules for the determination of historical values were carried out according to archetypes. However, in all these approaches described for the definition of building typologies, it is made clear that they are only there to make preliminary assessments for possible renovation measures and that they cannot replace planning based on individual case studies.

EU FP7 EFFESUS Methodology

The assessment methodology developed in EFFESUS was aiming at enabling the decision-making processes towards the energy renovation of historic districts using a decision support system. The methodology bases on three steps:

- Cultural heritage significance evaluation of buildings and districts in sufficient detail;
- Cultural heritage impact definitions of possible retrofit measures; and
- Balancing processes of cultural heritage significance with the impacts of retrofit measures to the cultural heritage value [26].

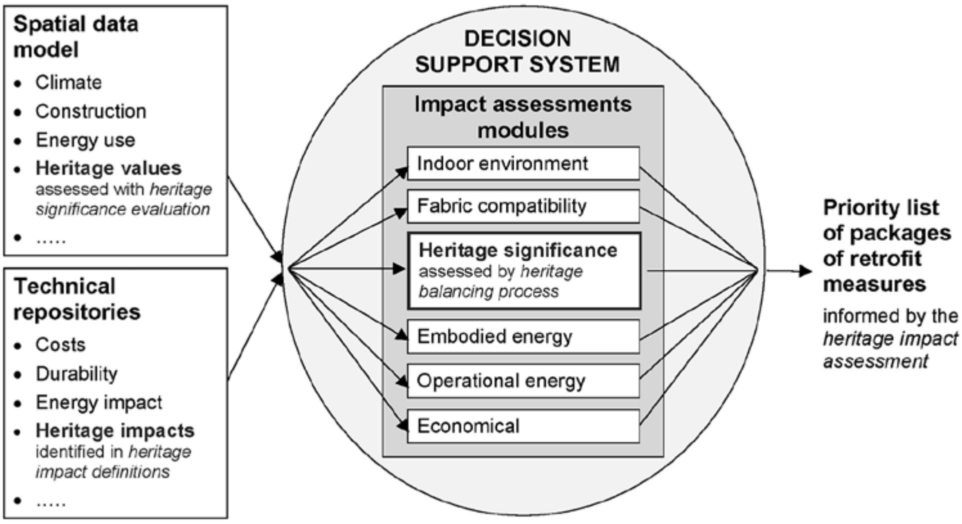


Figure 12 The EFFESUS decision support system, a software tool, uses two data input sets – a spatial data model and technical repositories – to interrogate, with six assessment modules, the various aspects of impacts of the retrofit measures. Source Hermann/Rodwell 2015, there Fig.1.

In the EFFESUS methodology, the heritage significance evaluation considers a variety of assessment locations (‘urban district’, ‘building exterior’ and ‘building interior’). For each of these assessment locations, the heritage significance is evaluated for three assessment types: visual, physical and spatial. All the evaluation is performed through a five-step scale to assign heritage significance levels: 0) Negative or neutral (or assessment not applicable); 1) Minor significance; 2) Major significance 3) Outstanding significance and 4) Exceptionally outstanding significance.

2.3.3 Attribute Significance assessment by L. Havinga [27]

While in EFFESUS different experts were asked to assign quantitative heritage significance levels to a predefined ‘checklist’, Havinga bases the expert interviews on visual material. (Figure 13) No predefined lists of attributes are set with the reason to include not only tangible but also intangible values in the assessment. Furthermore, the approach of Havinga is not considering the value itself but appraises the attribute and the aspects of an attribute that should be preserved. Although not obvious at a first glance, the difference is significant when it comes to practical use. In this way, the experts “translate” more theoretical considerations into practically applicable principles. At this, the architectural values of a façade are not to be included in the assessment process of a renovation, but rather the corresponding elements/attributes of the façade - from the proportions of the façade openings to the cornices, etc. - that are defined in concrete terms and are the true value-carriers. In her study about the Dutch post-war housing, Havinga uses a clear structure of visual material for the expert interviews on different scale levels (from the urban context to the architectural detail), to perform the Heritage significance assessment. The interviewees are asked to assign a value directly in the pictures, according to a predefined evaluation scheme (see Table 5).

Figure 13 Examples from the interviews established by L. Havinga for Dutch post-war-housing, published in the PhD work. ***Source*** *Havinga 2019*

Table 5 Predefined evaluation scheme, Source Havinga 2019

	High	Loss is considered unacceptable, and damage should be kept to the absolute minimum
	Medium	Loss or damage might be considered acceptable under special circumstances
	Negative	Loss or damage would be considered beneficial

Havinga's approach was considered promising for 4RinEU, as it could be well integrated as part of the 4RinEU Early Adopter Workshops. The results of these interviews following the Havinga approach were considered to be integrated into joint negotiation processes as described in chapter 3.3.1. What was not intended by doing these interviews was to replace existing expert assessments. Instead, the interviews should accompany the statements by heritage authorities and make the overall assessments suitable for integration within the planning process. The interviews were not only to be conducted with experts in heritage conservation but with all those involved in the planning process, in order to also capture elements worth preserving that are not subject to the traditional assessment according to heritage values.

The approach was tested in the Limerick/Ireland case study, but could not be fully implemented due to limited contact opportunities due to the COVID-19 crisis. Further details can be found in the description of the case study, see chapter 5.3.

2.3.4 Heritage Impact Assessment (3ENCULT)

Up to this point, approaches have been described that, to make decisions about solutions for the energy refurbishment of historic buildings, assume that the historic stock is evaluated in some way - be it as a building typology or also as a predefined approach to determining heritage values for the individual building. This assessment then serves as the basis for automated decision-making processes (keyword: decision support systems) or for the selection of refurbishment measures based on defined solution compendia. In the 3EnCult project, however, a different approach was taken, which does not start from the historic building but attempts to define a heritage impact assessment for technical solutions. This includes a description of how a solution interferes with the fabric of the building and its appearance according to defined criteria.
This includes, quite independently of the building, which physical, chemical and spatial/aesthetic impacts are to be expected for a specific technical measure. The assessment is done individually for every (technical) solution, preferably to specific archetypes.

In the 3ENCULT project, this approach of a heritage impact assessment was conducted in a rather generic way to evaluate the proposed technical solutions in their suitability for historic buildings. The rating was done in a structured template (Figure 14), which was not adjusted to

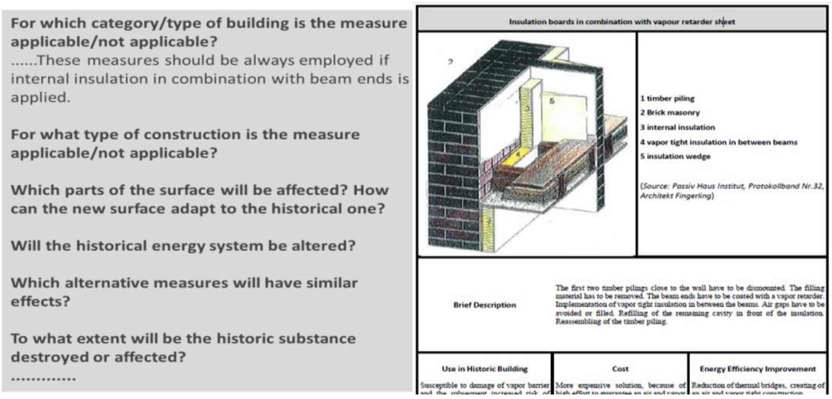
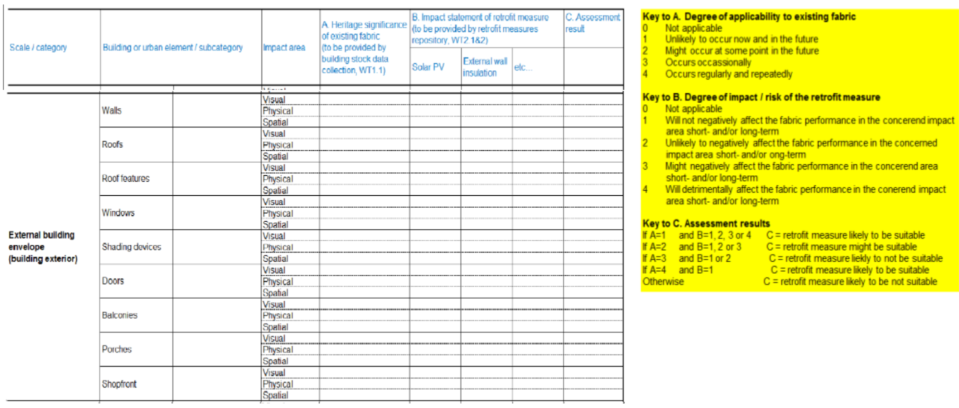


Figure 14 3ENCULT approach for the heritage impact assessment of energy retrofit solutions.

certain building types. It considers, like the EFFESUS assessment scheme (explained below) does, the impact of a certain solution concerning aspects like building structure, appearance, and reversibility (if a measure can be removed without damages) and is accompanied by information about costs and sustainability.

2.3.5 Assessment schemes for historic building renovation (EFFESSUS)



Scale / category	Building or urban element / subcategory		Impact area	A. Heritage significance of existing fabric (to be provided by building stock data collection, WT1.1)	B. Impact statement of retrofit measure (to be provided by retrofit measures repository, WT2.1&2)			C. Assessment result
					Solar PV	External wall insulation	etc...	
External building envelope (building exterior)	Walls		Visual					
			Physical					
			Spatial					
	Roofs		Visual					
			Physical					
			Spatial					
	Roof features		Visual					
			Physical					
			Spatial					
	Windows		Visual					
			Physical					
			Spatial					
	Shading devices		Visual					
			Physical					
			Spatial					
	Doors		Visual					
			Physical					
			Spatial					
	Balconies		Visual					
			Physical					
			Spatial					
	Porches		Visual					
			Physical					
			Spatial					
	Shopfront		Visual					
			Physical					
			Spatial					

Key to A. Degree of applicability to existing fabric
0 Not applicable
1 Unlikely to occur now and in the future
2 Might occur at some point in the future
3 Occurs occassionally
4 Occurs regularly and repeatedly

Key to B. Degree of impact / risk of the retrofit measure
0 Not applicable
1 Will not negatively affect the fabric performance in the concerend impact area short- and/or long-term
2 Unlikely to negatively affect the fabric performance in the concerned impact area short- and/or ong-term
3 Might negatively affect the fabric performance in the concerend area short- and/or long-term
4 Will detrimentally affect the fabric performance in the conerend impact area short- and/or long-term

Key to C. Assessment results
If A=1 and B=1, 2, 3 or 4 C = retrofit measure likely to be suitable
If A=2 and B=1, 2 or 3 C = retrofit measure might be suitable
If A=3 and B=1 or 2 C = retrofit measure liekly to not be suitable
If A=4 and B=1 C = retrofit measure likely to be suitable
Otherwise C = retrofit measure likely to be not suitable

Figure 15: EFFESSUS Impact indicators matrix for Historical Values and Conservation Principles (examples for exterior walls)

When assessing the applicability of technical solutions, the influence on monument values is only one aspect among many that need to be considered. Statements on energy efficiency, cost-effectiveness and technical feasibility are examined for the 4RinEU solution packages in relation to the archetypes using established KPIs (see Deliverable 2.1).

A variety of assessment schemes exists, also for historic building renovation. Within the EFFESSUS Project, the following categories of impact indicators for the implementation of new technologies in historical buildings and districts were identified:

- Indoor environmental conditions;
- Building and urban fabric compatibility;
- Historical values and conservation principles;
- Embodied energy;
- Operational energy;
- Economic return.

In general, one can divide the input datasets into two main groups: 1) Characterization of the heritage significance of historic buildings, and 2) Impact which the installation of retrofit measures will have on heritage significance.
While in the 3ENCULT project the focus was mainly on the first (Indoor environmental conditions), the EFFESSUS project considered both input datasets. Both datasets were

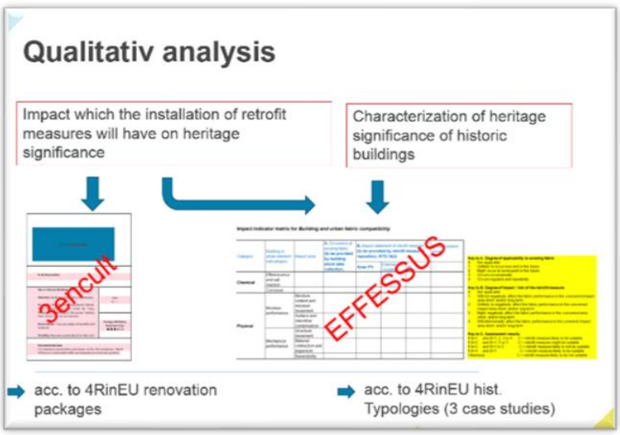


Figure 16 Schema describing the different approaches of impact assessment in 3encult and EFFESSUS

structured in the same way, using the same assessment locations and types. This allowed the systematic comparison of the two datasets. (Figure 16)

2.4 Cost effectiveness in historic buildings retrofit

One of the most important barriers in the implementation of energy retrofit measures is that the cost of potential energy, and therefore cost savings, are considered the main financial benefit. Anyhow, when it comes to the historic building case, more aspects are added to the discussion. Such aspects make the cost-effectiveness considerations even more challenging:

- Renovation of historic buildings is aiming at preserving cultural values, which have no equivalent in monetary terms but may cause positive effects (e.g. tourism, identity building etc.);
- Incentives as public financial support for the renovation can also be available because of the recognition as a listed monument, not given for the most ambitious renovation but for the compliance with the requirements set by heritage authorities
- The economic effects of historic preservation are not yet fully researched, because the final direct and indirect economic added value is not fully understood and the necessary data are highly diverse including Job creation, Household Income, Property Values, Heritage Tourism, Revitalization, Land use etc.

The report from the Getty Institute concludes that assessing the value of cultural heritage should include other tools from other disciplines, such as expert judgments, social assessments, psychological measures of attitudes and beliefs, laboratory experiments, participatory appraisal techniques, and marketing research methods.[28]

Energy-efficient renovation of CH buildings must consider and respect the socio-cultural values. However, such renovation will, if carried out properly with correct materials and with respect for the inherent values and qualities of the buildings and building environments, yield effects for the society that go far beyond the reduction of greenhouse gas (GHG) emissions. This is also the reason why the society invests in the renovation of historical buildings without demanding a direct energy-saving effect, and why historical buildings are often excluded from legislation on energy efficiency.

For individual technical measures or building renovation solutions, it is possible to estimate when the respective measure will have paid off.

Figure 17 shows an example from the EFFESUS project, which was provided by Alexandra Troi (Eurac research) at the EFFESSUS Venice Winter school in 2015.

Figure 17 This is an extract from a presentation given by Alexandra Troi at the EFFESSUS winter school "Sustainable Governance in UNESCO World heritage Cities" on 13 December 2015. It shows the economic effect of a window renovation/ replacement on a historic building. Source: Internal material provided by Alexandra Troi, Eurac research

As seen in the examples presented in Figure 17, the refurbishment/replacement of a historic window leads to varying energy savings depending on the performance of the existing windows, the share of window openings in the façade, the size of the building and related energy demand, and the climate. Depending on these parameters the payback time for the same intervention can be very different depending on the circumstances. Therefore, such estimates can only be made on a case-by-case basis and are not suitable for generalisation and implementation in a decision tool. The amount of data that would be required for a preliminary calculation of the cost effect is not proportional to the size of the buildings archetype cluster to be considered under the same conditions. At this, more emphasis should be placed on making calculation examples known locally and regionally to provide orientation for others, or on experienced consultants accompanying the planning process. Such calculation models may be linked to the building typology.

2.5 Prefabricated facades in historic building renovation

A core element of the 4RinEU renovation packages is the implementation of a prefabricated façade. This could be a reason to exclude the historic buildings in the project from the beginning, as was the case in the H2020 MORE-CONNECT project (https://www.more-connect.eu/more-connect/). In 4RinEU it was however decided to evaluate the use of prefabricated facades more in detail, also for the historic building stock.

Historic modular buildings

First of all, the group of historic buildings is interesting. They were originally built as modular systems. This includes e.g. post-war neighbourhoods if recognized for their cultural heritage value. N. Brito (2012) [30] refers to the report of the IEA Annex 50 – *Prefabricated Systems for Low Energy Renovation of Residential Buildings*, showing the potential for renovation with Prefab solutions. (Figure 18)

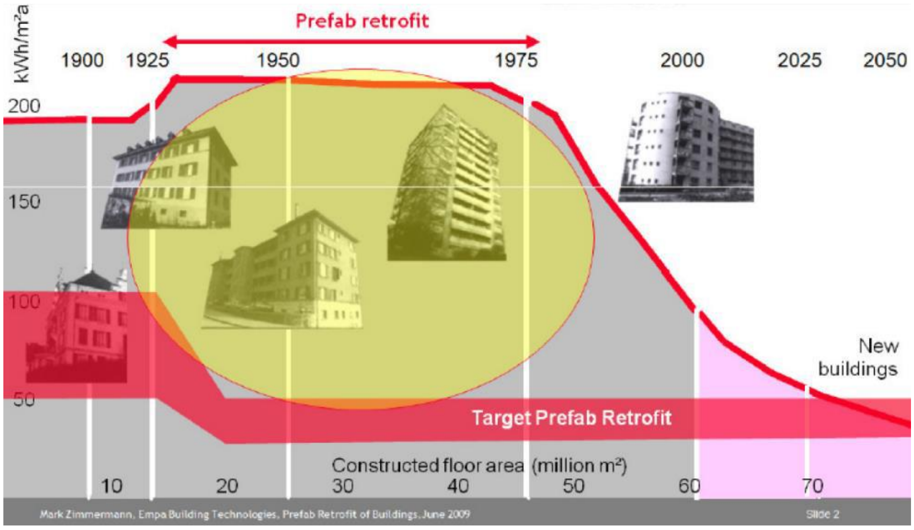


Figure 18 Estimated consumption in kWh/m2a (vertical axis, red line) of European buildings according to their construction decade and accumulated constructed floor area (horizontal axis, top and bottom). The "Target Prefab Retrofit" magenta bar illustrates the identified potential for savings in IEA Annex 503, and the superposed green dashed box on the bottom left demonstrates what optimized Historic Buildings, as described in this paper, can achieve.

At least a certain replicability of the façade elements can be assumed for such buildings, based on modular systems. However, to alter the surfaces of the façades will in many cases be impossible, and only possible in individual cases if the existing façade is not considered worthy of preservation.

Figure 19 Slate shingles as wall finishing in historic buildings

Historic buildings with cladded facades

A second group of buildings to take into consideration, are buildings with cladded facades. A variety of claddings exist in the historic building sector. One example is the wooden cladded facades of Nordic housing, another is slate shingles that you can find in central Germany. In modernist buildings, tiles are mainly used as façade cladding, sometimes also natural stone slabs. When it comes to refurbishing these buildings, it is often first considered to install external insulation in the space between the cladding and the wall behind it. This is very obvious from a building physics point of view. However, the practical implementation raises many questions. Usually, the existing historic claddings should also be used as the cladding of the new elements, since it is part of the protected structure with great impact on the appearance of the building. But removing and replacing the historic cladding in many cases is not possible without large damages. Furthermore, the space available for adding a new insulation layer between wall and cladding is very limited. And especially with the traditional buildings, another problem arose, as these façades are usually not regularly shaped and standardized prefabrication with a number of similar modules is not possible.

Historic buildings with unprotected facades

Figure 20 © Michael Flach, www.hiberatlas.com, Farm house Trins

There are experimental examples where prefabricated façades have been used for the renovation of historic, non-modular architecture. The geometrical fitting to the irregular façades is exploited through the use of 3D capture methods and corresponding manufacturing technology for the façade elements. One such example is the Trins farmhouse in Austria by architect Michael Flach, published at www.hiberatlas.com.(Figure 20) However, this is an exceptional case and a transfer of the method is only possible to a limited extent and only if the façade is not considered worthy of preservation, because although the rhythm of the façade is maintained, the proportions such as window depths are changed. If the architecture and aesthetics of a building are strong enough to withstand such an alteration, then a complete change of facades can be successful, seen from an energy efficiency point of view.

Buildings in a recognized historic area without designation as monument

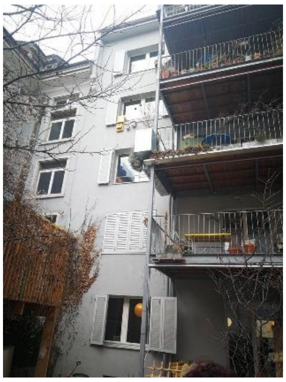


Figure 21© M. Mobiglia, SUPSI, www.hiberatlas.com, Apartment building Magnusstrasse - Zürich

If buildings are part of a recognized ensemble of buildings under heritage protection but are not themselves listed as monuments, the protection usually refers to the visible façades. Especially in the neighbourhoods of the second half of the 19th century or the beginning of the 20th century, the buildings are constructed as perimeter block developments, and partly form narrow inner courtyards. The apartment building in Magnusstrasse in Zurich, presented in the HiBERatlas (www.hiberatlas.com) is one of these examples. (Figure 21) For the renovation of these backyards, exceptions are sometimes approved by the heritage authorities. However, the backyards depend on the liveliness of their façades, small extensions, balconies, etc. Unifying entire backyards with the same façade element is not in conformity with the preservation of historic monuments.

3 The case of historic buildings in the 4RinEU project

3.1 Integration of Historic Buildings in the 4RinEU Effectiveness Rating Tool – a future scenario

In the past, some efforts have been made to support decision-making processes to obtain the best-fit solutions for energy-efficient renovation of historic buildings. (See chapter 3.3) Various systems have been developed to accompany the complicated process of balancing between the preservation of cultural values and the energy-efficiency of the measure and building. These efforts range from printed guidelines as a knowledge base for the decision-makers, to fully programmed online Decision Support Systems prioritizing certain solutions according to predefined algorithms. In common for almost all these instructions and tools, are the references to specific building typologies. In the IEA-SHC Task59 Subtask C, a dedicated working group was formed to perform an analysis of existing support tools. the support tools should not only advise the choice of a specific retrofit solution for historic buildings but also the packaging of these solutions while considering a variety of criteria.
In 4RinEU, a new decision-supporting tool was developed. It also considers the packaging of solutions for specific archetypes. It was however not designed for historic buildings and their related specific needs. In Figure 22, the parameter specifically related to the historic building stock for the tool are listed in the yellow arrows.

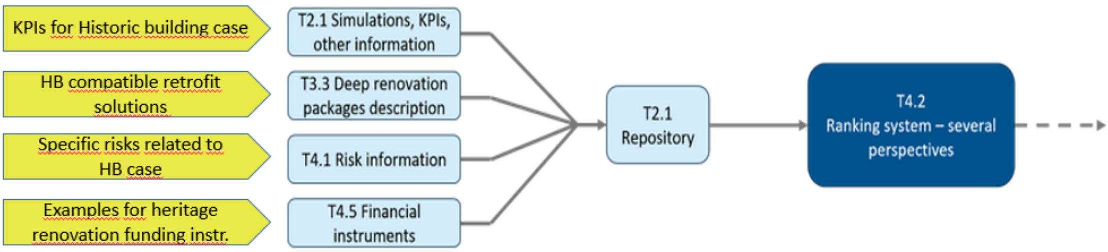


Figure 22 Structure of the 4RinEU Rating Tool (blue) developed for the decision support towards the selection of a 4RinEU renovation package depending on several input data (light blue). In the yellow boxes, the considered additional input data specifically for historic buildings are described.

In the following chapters, the identified parameters, as KPIs for Historic Buildings, HB compatible retrofit solutions, Specific risks related to historic buildings and Examples for funding instruments are assessed for their applicability. The assessment is visually supported on the base of the developed user interface of the 4RinEU Rating Tool.

3.1.1 Definition of Archetypes

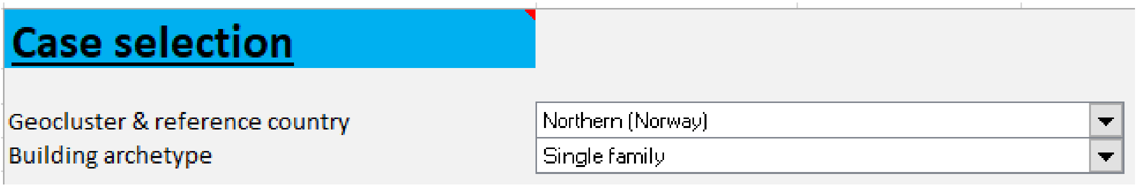


Figure 23 User interface of the 4RinEU Rating Tool – Case selection. Source 4RinEU, Deliverable 4.2.

Regarding the selection of the base case in the 4RinEU rating tool is limited to the selection of the Geo-cluster and the building archetype (single-family buildings, multi-family buildings). (Figure 23) The level of detail for the selection of case studies would have to be significantly higher for historic buildings. The associated urban planning situation has a high impact on the decision making for historic buildings, for example, whether the buildings are located in a densely built-up inner-city district or stand-alone buildings in the suburbs. In the process of the 4RinEU project, the Case selection was limited to the fixed two archetypes for each Geo-cluster to be able to perform the simulations and parametrisations of all possible 4RinEU packages. Even if only few historic building types, which could cover a large share of the historic building stock, were to be included in the tool, this would mean an enormous additional effort for parameterisation.

3.1.2 Selection of the USER PRIORITY

In the tool, the user can select the level of the own priorities regarding Economic issues, Energy, Environment, Building Site Management, and Comfort and Indoor Air quality (Figure 24). The scale goes from 1(low priority) to 5 (high priority). If the tool should also work for the use in historic building context, another item should be introduced on "Heritage preservation issues". With this, the user could give priority also to the preservation of the facades or the impact on historic structure. The related KPIs which serve as input for the parametrisation for that new priority "Heritage preservation issues will be described in the next chapter 4.1.3.

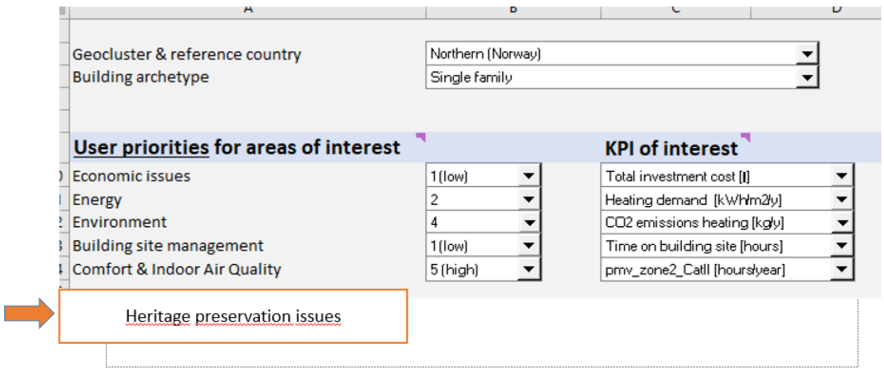


Figure 24 User interface of the 4RinEU Rating Tool – User priorities selection and KPIs of Interest. Source 4RinEU, Deliverable 4.2.

3.1.3 KPIs related to Cultural Heritage issues

If it is assumed that historical building issues can be selected under the user priorities, also the KPIs associated with this parameter would have to be defined and quantified. The already set KPIs in 4RinEU are focusing on five topical areas:

- economics,

- energy,
- environment,
- building site management,
- comfort and internal air quality.

Some of these KPIs can be considered in the same way in historic buildings, some of them would require revision/extension, which is demonstrated in Table 6.

Table 6 List of the KPIs defined for the decision making in the 4RinEU project and possible application to the historic buildings' context.

Topic and KPI name	**Explanation with specific relation to historic building issues**
Energy	The same KPIs can be considered, set of the boundaries according to a new defined historic building archetype
Environment	KPIs regarding the CO_2 emission are considered the same, but in relation with historic city centres more environmental impacts are important: e.g. living and working in the historic centre can reduce the environmental impact of traffic.
Comfort & IAQ	These KPIs do not vary between different building types – historic and non-historic
Economic issues	The nature of the KPIs can stay the same. For historic buildings, a longer live span should be considered (more than 50 years), the benchmarks will differ significantly with a historic archetype, data are not available (with only few exceptions), costs in the historic building sector depend much more on personnel costs than on the cost of materials compared to normal renovations, as they often use customised solutions.
Building site management	Can stay the same, but from experience, the time for side-work is higher because of the necessary customisation of the solutions

There are hardly any examples of the additional integration of KPIs specific to heritage issues in that kind of evaluation schemes. One of the examples was shown above with the EFFESSUS Decision support system. However, this requires a precise analysis of the building stock to be considered, e.g. a neighbourhood, in order to determine the criteria for consideration.
Another approach was developed in the Interreg Alpine Space project ATLAS [31], but here with another purpose: For renovation plans the assessment schemes can inform about the overall sustainability of the solution – thus it is made to evaluate solutions and not to find the most suitable solution. However, the ATLAS KPIs demonstrate an approach, how quantitative and qualitative analysis can be merged in one assessment scheme.
The ATLAS KPIs are defined according to 5 main categories:

- Use of original materials (in %)
- Compatibility with cultural values (according to professional assessment)
- Rate of reversibility of renovation solution
- Use of original structure (in %)
- Integration of qualified interdisciplinary team (diversity of the involved)

These types of KPIs and rating schemes, both from EFFESSUS and ATLAS, cannot be integrated into the existing 4RinEU rating tool.

3.1.4 User Specification for construction process

The user specification for the construction process in the 4RinEU Rating Tool is focused on aspects in relation with the application of the prefabricated façade. (Figure 25) However, also other technologies are part of the 4RinEU renovation packages, the prefabricated façade is the

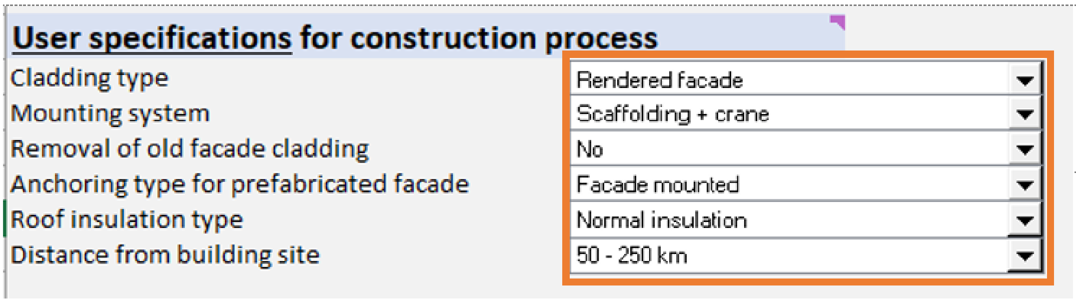


Figure 25 User interface of the 4RinEU Rating Tool – User specification for construction process. Source 4RinEU, Deliverable 4.2.

most impacting technology. Regarding the historic building stock, the application of a prefabricated façade is therefore also the most controversial one in the 4RinEU packages.
The pre-selections given in this respect in the "Cladding Type", Mounting System" and others are therefore insufficient for work with historic buildings. At this point, the tool would have to offer an in-depth extension with many more choices. Some of the parameters possible to add – not only related to heritage issues but also to the situation in the urban context - are listed in Table 7 (list not complete). What is not reflected at all in the tool and what should be considered not only for the historic building case is the different treatment of the single sides of the building.

Table 7 List of the User Specifications defined for the decision making in 4RinEU Rating Tool and possible application to the historic buildings' context

User specification	**To be added to existing options**
Cladding Type	Decorated facade, untreated façade, …
Mounting System	Alternatives if backyard is not accessible, with narrow street,
Removal of old facade cladding	Change of existing façade not allowed, Different treatment of the facades!
Anchoring type for prefabricated facade	Not possible
Roof insulation type	Insulation of the upper ceiling, …
Distance from building site	

3.1.5 Financial instruments

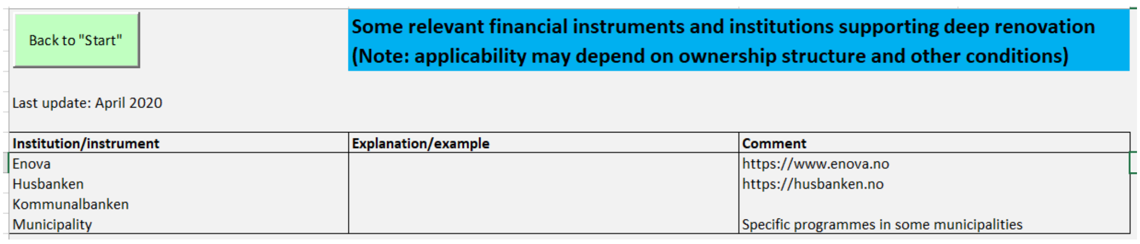


Figure 26 User interface of the 4RinEU Rating Tool – User specification for construction process. Source 4RinEU, Deliverable 4.2.

In another tab of the 4RinEU Rating Tool, information is provided on financial instruments to promote refurbishment to low-energy standards. (Figure 26) However, these instruments are only listed informatively and are not included in the calculation and parameterisation resulting in the most suitable 4RinEU Renovation package. It was not possible to provide the necessary data entry since the corresponding instruments change quickly and are also structured very differently from country to country.

In almost all EU countries, there are special subsidies for the additional costs of monument preservation; in only a few is the subsidy for energy refurbishment specifically adapted to the historic building stock. Therefore, funding instruments cannot simply be transferred; a separate analysis would be necessary. However, since the funding instruments were not directly included in the rating tool, but are only provided as references, a detailed list was not provided here.

3.1.6 Risk management

The direct quantitative risk evaluation of each deep-renovation package was considered far beyond the scope of the 4RinEU project. Therefore, also the detected risks are considered in a descriptive way in an extra tab of the 4RinEU rating tool and not as direct data entry in the calculations/parametrisations. Reasons for the decision were e.g. the requirement of many details to be gathered such as the probability of the risk, costs of potential damages (and their repair) and costs of remediation or mitigation. For the historic building case, the general approach to risk assessment has been built on and in Table 8 several additional risks are listed regarding the historic building renovation. The list is by no means to be regarded as complete, as the diversity of the problems that arise is even greater due to the inhomogeneous historical building stock.

Table 8 List of the risks assessment defined in 4RinEU Rating Tool and possible extension to the requirements of the historic buildings (blue)

Prefabricated multifunctional facade				
	Risk management, examples:			
	Event / cause	*Possible outcome*	*Countermeasure*	Affected KPI
	Elements of the Facade worthy of preservation	Destruction of valuable historic elements	Limiting of the area to apply the prefabricated Facade	Heating demand, Building surface material, Building historic structure
	General advice:			
	Historic buildings are often protected because of the heritage value of their facades. Therefore in many cases, the application to the main visible facades will not be possible. In some cases, an application to the back facade can be assessed. In few cases also a compatibility with the historic facade is possible, e.g. if there is a historic prefabricated facade in situ and has to be dismantled because of structural damages.			
	An integrated planning process is recommended – In any case an expert or a team of experts with competences in both, technical issues as well as cultural heritage preservation, has to be involved already in the planning process.			
	Use appropriate collaboration contracts where possible			
	Be sure to include the behaviour of the complete building in the planning process			

	Be consequent in the remediation of thermal bridges			
	For the building process, the best result will be achieved without inhabitants in place			
Plug and play energy hub				
	Risk management, examples:			
	Event / cause	*Possible outcome*	*Countermeasure*	Affected KPI
	DHW too hot	Scalding	Limit temperatures at "endpoint"	
	Legionella spread	Serious infection		
	No specific requirements for the Plug and Play energy hub			
	General advice:			
	Detailed management of energy loads and sources enables matching loads with the best (cheapest) available energy source, mapping demand and distributing costs			
	Pay attention to the implementation of the pipes, the use of already existing openings, such as old chimneys etc., is recommended in order to reduce the destruction of any structures that may be worth preserving.			
	Pay attention to communication (bus) and electrical connection as well as hydronic system			
RES: PV cells and solar collectors; applicable for DRPs MFH_NO_RP15493, MFH_NO_RP15349				
	Risk management, examples:			
	Event / cause	*Possible outcome*	*Countermeasure*	Affected KPI
	Possible PV/ST field is limited to a small area	Lower economic value of installation	Use of Early Reno	PV power
	Historic roof structure structurally not suitable for bearing heavy loads	on-roof solutions are not possible	Involvement of expert in the planning, considering Roof integrated solution	
	Requirements of heritage authorities only allow certain element designs, e.g. red colour etc.	Efficiency is limited	Involvement of expert in the planning, check market for new innovative solutions	
	General advice:			
	Use Early Reno tool before design choices with high economic impact are made			
	The installation on neighboring and outbuildings should be checked			
	For historic city centers and rural regions, solar registers are sometimes available which already contain information on aspects of heritage conservation			

3.1.7 Applicability of the 4RinEU Rating Tool for the historic buildings

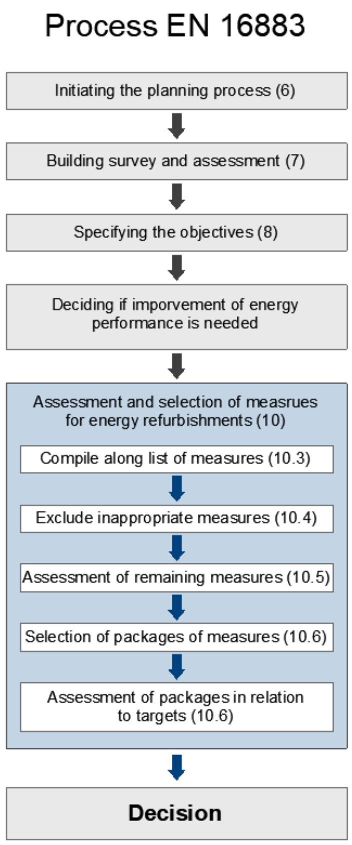


Figure 27

A final assessment must be made whether the 4RinEU Rating Tool can be adapted to historic buildings and to what extent it would then have to be extended and modified. The Tool as it is structured in 4RinEU aims at the definition of the most suitable renovation package (out of a pre-setting with 4RinEU technologies) according to influencing parameters selected by the user.

The establishment of defined renovation packages as selection options for historic building renovation is not practiced, at least the authors are not aware of any example of this. Instead, attempts are made to compile a long list of individual measures that best suit the building under consideration. So there is a pool of possible solutions that are combined in different ways.

Various tools tailored to the historic building stock (see chapter 3.1) either try to preselect solutions for certain building typologies or offer methodological decision-making support for the balancing of aspects of historic preservation and energy efficiency.

It is particularly important with historical buildings to include alternatives in the selection options. In general, the application of EN 16883 is recommended here. The standard is not aiming to set targets in numbers for the energy demand but describes the approach towards an energy-efficient renovation of historic buildings. One of the core messages is the flowchart of decision making (Figure 27), which recommends the creation of a long list of possible solutions, in which the appropriate solution for the individual building can be filtered out in an integrated planning process. As the selection process is very complex and the overall process cannot be implemented for all renovation projects, tools and guidelines have been developed at regional/national level to facilitate this selection process (e.g., the Responsible retrofit guidance wheel for the UK http://responsible-retrofit.org/greenwheel/). These tools provide solution packages for individual historic building types). A rating tool that would be applicable to the historic building stock would therefore have to include the solutions that come into question for the specific archetypes.

The only way to include the special requirements of historic buildings in the 4RinEU rating tool would be to have more detailed settings in the pre-selection so that certain solutions can either be excluded from the beginning or the effort of their adaptation to the special case can be included in the rating.

With the limitation of the 4RinEU Rating tool on MFH and SFH the differentiated consideration of the historic building stock cannot be achieved. To give one example: Although the building in Norway is an apartment building, it is integrated into a narrow urban context and therefore different from the archetypes considered so far in the 4RinEU tool.

Furthermore, a parametrization of all possible renovation packages also for the historic building case would go far beyond the justifiable efforts within 4RinEU. Since for the vast majority of historic buildings, the prefabricated façades cannot be used for completely different reasons, a pre-analysis to evaluate if an additional façade element is suitable in general for the building or not could be inserted as access question to the 4RinEU tool. In this way, the number of archetypes to be considered in the 4RinEU Rating Tool would be reduced to a manageable number.

3.2 4RinEU Historic Building Case Studies: A qualitative analysis

For the following three case studies – all historic buildings - a qualitative analysis was carried out to assess the applicability of the 4RinEU renovation technologies. For this analysis, regionally available solution repositories (as described under 4.1.7) and recommendations for the specific building types were researched. The qualitative analysis was based on the knowledge about the historic building and the related building typology.

3.2.1 Case Study 1, Norway: Sven Brunsgate 5, Oslo

Description of the Building

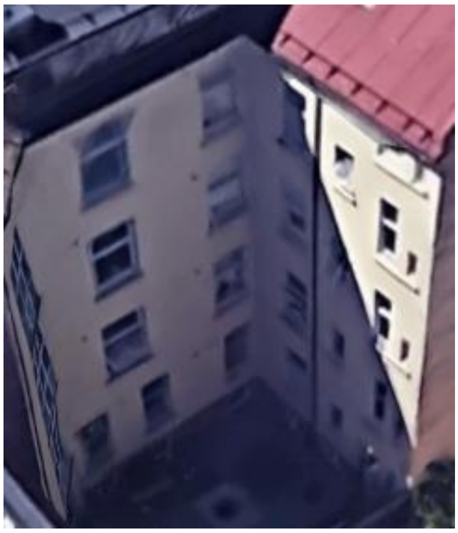


Figure 28 Screenshots of GoogleMaps on Sven Brunsgate 5, Oslo.

The building is listed in the yellow category by the Cultural Heritage Management Office of Oslo. It is situated in a perimeter block development typically for the urban expansions of the second half of the 19th century in the core of Oslo. (Figure 28) The building is composed of two parts in an L-shape: the main building with the front facade is oriented to the street, the appendix building is facing the backyard. The walls consist of a solid brick construction, plastered at the back. The main façade is exposed brick with the typical historic façade design: cornices, clad sandstone plinth and window eaves. The main features of the building regarding geometry and energy are summarised in Table 9.

Table 9 Main parameters of Sven Brunsgate 5, Oslo regarding geometry and energy as asked in the query of the 4Rin EU Rating Tool

Protection level	Listed 1/1/1990 in the yellow category as buildings that should be conserved
Energy Consumption	ca. 175 000 kWh (300 000 kWh is listed for two buildings, Sven Bruns gate 3+5)
Area:	ca. 700 m2 (1200 m2 for Sven Bruns gate 3+5)

Number of units:	8
Area per Floor:	123+57=180m²
Building Height:	ca 13m
Building Width:	ca 11m
Building Length:	ca 14m
U-Value Wall:	no information available

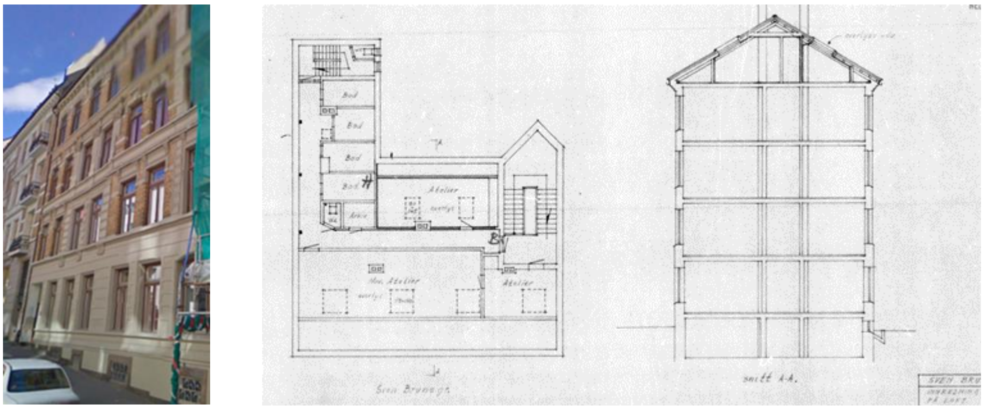


Figure 29 Street façade of Sven Brunsgate 5 (left, Source: Open Street View) and Floorplan/Section 1968 (right, Source Boligbygg Oslo)

Definition of the Archetype

Brick buildings like Sven Brunsgate 5 were all listed in Oslo in the 1990s. They are part of Oslo's homogeneous brick buildings. This kind of buildings were all listed as a direct consequence of a Royal resolution from the 1990s stating that these kinds of buildings characterize the city, and thus should be preserved. The brick yards from the 19th century are some of the most typical buildings of Oslo's city and street scenes. Usually, these buildings have plastered and painted facades that require regular maintenance. Originally, the buildings had only natural ventilation. The air was drawn out via the chimneys of the fireplaces. Mechanical ventilation usually has been installed later with extractor fans in bathrooms and kitchens. The primary heat sources were iron stoves, and in lavish homes, tiled stoves. The kitchen was normally heated by a wood stove, and each living room had a cast-iron stove, which was fired with wood or charcoal. The advantage of the tiled stoves was that they had a better heat storage capacity.[32]

Table 10 Parameters for the Archetype of Sven Brunsgate 5, Oslo according to the 4RinEU archetype definition (Information for the building type were taken from the Tabula classification, the CoolClim project and the report…

	Geo-cluster: Building type:	Norway Murgårder
	Building size class	Most similar building typology out of the 4RinEU Archetypes: TERRACED HOUSE (TH) Lateral sides are set as ADIABATIC Reference floor area: 88 m2 Floor Height: 2.8 m
	Construction Period:	ca. 1850 – 1920
	Reference Floor Area (heated area):	600

 	Volume [m3]	
	Number of apartments	8
	U window [W/(m2K)]	U window 2.6
	Uwall [W/(m2 K)]	0.82
	Envelope surface [m2]	440+118 (window+door) 2 adiabatic walls
	Uroof [W/(m2 K)]	0.81
	Surface roof [m2]	142
	U basement [W/(m2 K)]	0.55
	Surface basement [m2]	142
	Current heating boiler	Decentralised, stoves in single rooms
	Typical construction elements	Wooden roof construction Floors in wood, possibly filled with clay or coke dust, anchors along the gables. Exterior walls in load-bearing bricks, stepping wall thickness upwards. Load-bearing central wall in brick ("heart wall") Other interior walls in wood or brick. Basement wall and foundations of natural stone Wooden piles if the construction could not be founded on solid rock.
	Others	Decorated Facades towards the street, Street facades without distance to the public space

Heritage protection

In the Birkelunden area, for example, 139 apartment buildings were protected as an urban ensemble. No specific regulations were issued for individual buildings, but regulations for all buildings within the protected area. These concern in particular the exterior envelope (walls, windows, roof) and partly also the stairwells. The vast majority of brick buildings from this period, including the selected example, were built according to the same basic principles.

Compatible Solutions for the Archetype

To provide guidance on possible solutions for the specific type of building, reference is made to the work that Researchers from SINTEF and the Norwegian Institute for Cultural Heritage Research (NIKU) have done [33]. The aim was to define a number of proposals for measures that can be used for Norwegian buildings worthy of protection, and in addition have relevance in other existing buildings. The work was mainly based on investigations in a larger conservation area, called Birkelunden, which is in building time and structure very much comparable to the district of Sven Brunsgate 5. The focus of the CulClim project was on apartment buildings from 1850–1920, but the advice may also be relevant for younger buildings and can be transferred also to other cities. Older apartment buildings often have moisture problems, as well as draughty and cold apartments in winter. A special feature of the area is the subsoil, which consists mainly of moist loam, the reason why timber rafts were used for foundations to stabilize the ground. Special attention is therefore given to the raising damp issue and the existence of water in the basement and backyard. Therefore, it is important to give the owners not only guidance on technical solutions but also informing the owner/tenants about possible damages and ways for maintenance.

In summary, the following solutions can be implemented/not implemented in the Archetype:

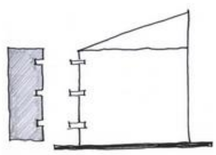
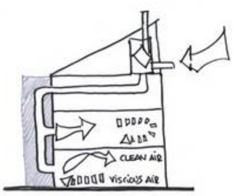
- NO exterior insulation allowed
- Change of the windows only with permission (NOT allowed, if the facade is protected) e.g. if windows have been changed many times before, and those in place, are of poor quality
- Seal, insulate and repair the windows.
- If new plaster is necessary, this has to be specifically adapted

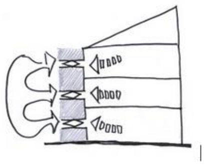
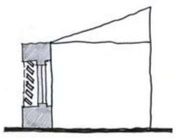
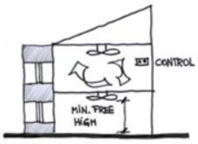
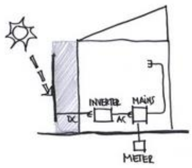
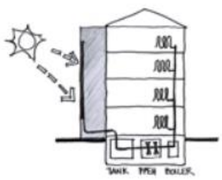
Application of 4RinEU solutions

The guidelines presented above, elaborated in dialogue with a whole range of stakeholders, already show that the application of 4RinEU technologies is only possible to use in Murgårder buildings to a very limited extent. Even if an implementation can be considered in one or the other case, this is certainly rather an exception and can hardly serve as a standard solution, which is suitable for the application in the historical buildings. The great advantages of prefabrication - with cost efficiency, less disruption to the users, etc. - are not applied here since the evolved building structure and typical elements of the building envelope always require on-site adaptation.

Additional implementations of 4RinEU technologies are limited. In the following table you will find a qualitative analysis:

Table 11 Qualitative analysis of the applicability to the historic Case Study 1 of individual components from the 4RinEU solution packages from the perspective of heritage preservation

 Prefabricated Façade	In general, not possible due to the protection of the façade and the limits regarding the overhang to the public space (pedestrian). In some exemptions, an application in the backyard can be considered, but due to irregular facades and only limited area, the replication potential of prefabricated solutions is very low. Furthermore, the construction details like the roof eaves and windows need detailed planning. Problems with raising dump as described above have to be taken into account.
 Balanced AHU/HR	Centralized ventilation machines aim to guarantee the proper ventilation rate within the building and can be considered valuable in many cases, especially in historic buildings described here. Special attention must be paid to the placement of the ducts because of the existence of decorated ceilings etc. For the vertical distribution, usually, chimneys etc. can be used, so there is no need for mounting it to an exterior façade element. The bulky machines can usually be placed in the attic if this is not used as a flat.

 Façade Integrated Ventilation/HR	A façade integrated and decentralized ventilation system, as foreseen in the 4RinEU package, will not be suitable for the archetype considered here. As the ventilation units are placed in the window opening, this would change the existing window size. Even in case of the replacement of existing windows (because of poor performance and low heritage value) a change of the window size would not be considered feasible.
 Integrated Shading	Despite the fact, that shading systems in northern countries have not the high importance as in warm climate areas, the integrated shading in prefabricated façade would only be considered for the backyards. Because of the urban structure of this archetype, the backyards are winding structures with many outbuildings and extensions, in which the sunlight only reaches the façades to a very limited extent.
 Smart Ceiling Fan	As described above, many of the brick buildings in Oslo are only protected for the appearance to the outside and the stairwells. The application of a smart ceiling fan would therefore be feasible from a heritage point of view, even more, if this is considered a reversible measure. The need of a cooling system in the Northern Geo-cluster is discussed elsewhere.
 Building-integrated PV/ST	Building-integrated PV systems should not be excluded per se also in a historic context. The positioning has to be done very carefully. Non-visible surfaces or outbuildings can be taken into consideration. This also includes a careful integration in the facade, all the more if this façade is a new addition to the existing. However, these remain exceptions and can only be decided on a case-to-case basis. If PV systems are installed on the roof, only well-designed integrated solutions can be considered.
 Energy HUB	The Energy Hub is a hydronic system able to manage complex heating and cooling systems. It can be used in combination with a solar-thermal system, as well as with a heat pump and can properly control the heat fluxes depending on the required needs (see D3.3). The Energy hub can be used independently from the prefabricated façade.

3.2.2 Case study 2, Netherlands: An industrialized, lightweight, prefab system in Amsterdam

Contrary to the original planning, no building from the 4RinEU Case Study providers Woonzorg was chosen as an example in the Netherlands. This was partly due to the change of partner and the fact that communication only started up again afterwards. Furthermore, the buildings did not seem suitable for the consideration of the historical case.
However, it was possible to draw on Lisanne Havinga's PhD thesis “Advancing Post-War Housing. Integrating Heritage Impact, Environmental Impact, Hygrothermal Risk and Costs in the

Renovation Design Decision" [34], which deals with the rehabilitation of post-war housing estates. The thesis was kindly made available to the project by Lisanne Havinga for this purpose. The choice was supported by several aspects:

- The approach developed by L. Havinga for the identification of heritage values and their inclusion in renovation planning was adopted in the 4RinEU activities (see example Limerick/Ireland);
- A heritage attribute assessment has already been carried out for the selected case study and serves as a basis for consideration;
- The building type under consideration is a system building that has been implemented many times in this way or in other modules and therefore has a high transferability potential;
- Post-war housing estates are recognized to have one of the highest potentials for energy saving.

Building history and description

As in the Oslo case study, the definition of the building type is closely related to the urban development. The building is part of a neighbourhood of the Western Garden Cities in Amsterdam, with a large post-war urban expansion of the city. The district of Slotermeer, completed in 1954, is one of the most authentic parts of Nieuw West.

The plans for the area were drawn up by Cornelius van Esteren in the first half of the 20th century. The guiding idea was no longer the closed block development of the Amsterdam School, but the striving for light, air and space in architecture. As a building of interest for the study was designed by architect Berghoef and erected in 1953 as an industrialized precast concrete system (the Airey system). The ensemble consists of 13 buildings, which are positioned in a series. As Havinga shows, some of the buildings have already undergone significant transformations over time, including the replacement of the steel window frames or the painting and plastering of the wall cladding. (Figure 30)

Figure 30 Other buildings in the ensemble of the Amsterdam case study that have undergone significant transformations over time, resulting in a negative impact on the significance (Source: Havinga, 2019. P. 166)

The unifying characteristics of the construction method, which at this point should also stand for the building typology, are defined by modular floor plan structures. (Figure 31) The following features describe the building typology:

- Unique, industrialized, lightweight, prefab systems
- Social Housing neighbourhood
- Ground floor with two-room apartments (ca. 41 m²) and three-room apartments (ca. 45 m²)
- storage rooms (4.5-5.5m²) between the dwellings
- Second/third floor with 4-room apartments (ca.65m²)
- Balconies on the garden side
- In total 255 apartments in the 13 Airey-blocks of roughly 14.000 m² NFA.[35]

Figure 31 Ground floor with apartments of the Airey-buildings. (Hooyschuur) Source: Kist b2016

Heritage value

The Airey system was strongly spread in the Netherlands. Only in Amsterdam, 5000 of these blocks were constructed. The neighbourhood in question is remarkable for the urban situation and the relation to the greenery. During the attribute significance assessment undergone by 4 preservation experts, a high significance was assigned to many attributes. The assessment concluded that almost the entire external appearance should be preserved.

The buildings do not have a monument status, still, they are recognized as valuable and they are situated in a listed conservation area. There were already plans to demolish the buildings. These plans were however put aside due to protests from the population and heritage groups, which is quite remarkable.

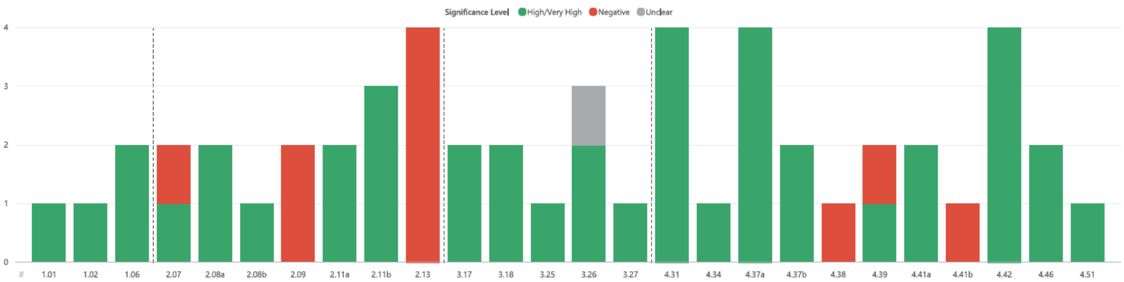


Figure 32 Result of the Attribute significance assessment: 4.31= External Wall Cladding – Concrete Panels (Rhythm and Adherence to System)/ 4.37a = Window Frame – Steel (Slim Profile)/ 4.42 = Eave. (Source: Havinga 2019, p. 176)

In the expert interviews, which were carried out by L. Havinga, the most recognized elements have been (Figure32):

- The external Wall Claddings
- The window frames
- The eaves

Significant patterns of the panels and panel size corresponding to the size of the window openings were highlighted by the interviewees. Due to the attribute value of the windows, the experts wanted to maintain the visual appearance of the window frames. In addition, they considered an aesthetic quality in the panel fastening system which reflects the lightness of construction.

It is interesting to note, that the experts mostly referred to the 'visual' appearance and considered the replacement of the fabric not necessarily problematic. This even affected the unique construction system, for which the preservation of the exterior appearance was deemed sufficient [34].

Recommended solutions for the case study

After the demolition was averted and the façade was recognized as a heritage object, the Havinga study - which was based on concrete plans for measures - ruled out external insulation from the outset. Furthermore, during the heritage significance assessment of other post-war buildings, the application of external insulation to the side facades of the building blocks was highly negatively evaluated by the experts.

The application of internal insulation needs a detailed planning and consideration on the hygrothermal risk. There is still a lack of knowledge in applying internal insulation in that type of construction. Interior insulation will be inserted in the inner shell of the construction, thus there is no reduction of the dimensions of the premises. The planned standard analysis is associated with high costs. Having identified the following measures that can both meet the technical requirements associated with the existing lightweight construction and are feasible from a historic preservation perspective

- Internal insulation
- External insulation applied to the roof.
- Original balconies replaced because of the structural problems
- Steel window frames replaced with aluminium window frames with slim profiles.
- Air to Water Heat Pump with Convectors
- Mechanical Ventilation with Heat Recovery
- Cooling not common in the Netherlands and therefore not included in recommendations
- No restriction was placed on the installation of PV panels on the roof

Furthermore, based on a parametric study it was stated, that the type of HVAC system is the dominant factor in determining the operational CO_2 emissions. This fits in with the general knowledge of dealing with historic buildings - building services have an enormous influence on the efficiency of the renovation. And in many cases, an efficient HVAC is feasible with the protection of the heritage values.

Test of building archetype in 4RinEU Rating Tool

The 4RinEU Rating Tool was tested with the MFH for Netherlands, which is the best comparable to the historic building archetype considered here. Therefor the basic parameter for the lightweight prefab building in Amsterdam are compared to the 4RinEU Archetype of MFH Netherlands in Table 12.

Table 12 Parameters for the Archetype of Case Study 2/Amsterdam, according to the 4RinEU archetype definition (Information for the building type were taken from Havinga 2019)

	4RinEU Archetype MFH Netherlands	Historic building Archetype Netherlends (Tabula NL.N.AB.01.Gen.ReEx.001)
Construction Period:	1955-1975	1953 (...1964)
Reference Floor Area (heated area):	3,456.00	1080 (2033)
Volume [m3]	10,368.00	2700...
Number of apartments	32.00	20
U window glazing [W/(m2K)]	2.38	U Window (5.2/2.9)
U window frame [W/(m2K)]	2.10	
Uwall [W/(m2 K)]	1.64	(1.61)
Envelope surface [m2]	2,016.00	(462)
Uroof [W/(m2 K)]	1.48	(1.54)
Surface roof [m2]	864.00	(501.9)
U basement [W/(m2 K)]	1.97	
Surface basement [m2]	864.00	
Current heating boiler	Traditional Gas Boiler	(individual gas-fired boiler)
Total Efficiency of the current heating system	0.67	

In a next step, the 4RinEU Rating Tool was used inserting the data of the 4RinEU Archetype MFH Netherlands, the user priorities were set to fulfil the requirements of the case study considered here best. (Figure 33)

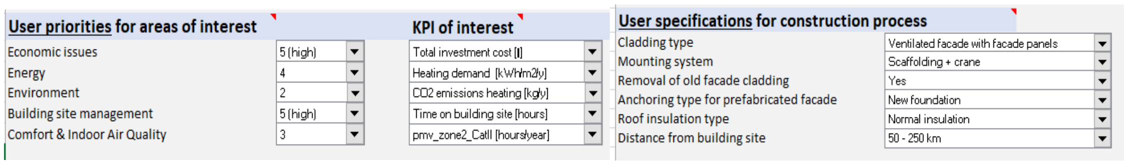


Figure 33 Interface of the 4RinEU Rating Tool with the presetting for the Case Study 2/Amsterdam in this report.

The parameterization of the 4RinEU archetype in the Rating Tool provides a statement about which of the 4RinEU solution packages is best applicable under the given premises. (Figure 34) However, as the tool is currently designed, it does not include architectural quality or preservation issues in the calculation (See chapter 4.1). The output of the 4RinEU Rating Tool

Results overview

		Percentage	Pre-/no reno	Standard	MFH_NL_RP20209	MFH_NL_RP20221	MFH_NL_RP20168	MFH_NL_RP20227	MFH_NL_RP20353
Combined score (max = 10; low values = good)				4.66	4.92	4.95	4.98	4.99	4.99
Economic issues	Total investment cost [€]	0.263	0	552,359	1,367,125	1,396,538	1,416,225	1,496,022	1,429,333
Energy	Heating demand [kWh/m2/y]	0.211	107	79	11	10	34	9	11
Environment	CO2 emissions heating [kg/y]	0.105	111,000	81,983	8,680	7,850	26,300	6,720	6,251
Building site management	Time on building site [hours]	0.263	0	610	959	959	924	959	959
Comfort & Indoor Air Quality	pmv_zone2_CatII [hours/year]	0.158	222	340	651	656	294	612	651

Back to "Start"

Result details
(out of 288 simulations for MFH, NL, 50 km - 250 km from building site)

Renovation package ID	Pre-renovation	Standard renovation	MFH_NL_RP20209	MFH_NL_RP20221	MFH_NL_RP20168	MFH_NL_RP20227	MFH_NL_RP20353
Ranking			1	2	3	4	5
Combined score (max = 10; low = good)		**4.658**	**4.920**	**4.946**	**4.979**	**4.988**	**4.993**
Total investment cost [I]	0.00	552358.90	1367124.60	1396538.04	1416225.04	1496022.04	1429332.60
Heating demand [kWh/m2/y]	107.00	79.02	11.20	10.20	34.00	8.70	11.20
CO2 emissions heating [kg/y]	111000.00	81983.23	8680.00	7850.00	26300.00	6720.00	6251.24
Time on building site [hours]	0.00	609.50	958.75	958.75	924.48	958.75	958.75
pmv_zone2_CatII [hours/year]	222.00	340.00	651.00	656.00	294.00	612.00	651.00
Deep renovation package technologies							
Facade	PRE-RETROFIT EXTERNALWALL	POST-RETROFIT ETICS FACADE (U=0.2)	POST-RETROFIT GOOD PREFABRICATED FACADE (U=0.2)	POST-RETROFIT VERY GOOD PREFABRICATED	POST-RETROFIT GOOD PREFABRICATED	POST-RETROFIT VERY GOOD PREFABRICATED	POST-RETROFIT GOOD PREFABRICATED
Window	PRE-RETROFIT WINDOW	POST-RETROFIT low E double glazing	POST-RETROFIT low E double glazing	POST-RETROFIT low E double glazing	POST-RETROFIT triple glazing	POST-RETROFIT triple glazing	POST-RETROFIT low E double glazing
Roof insulation	PRE-RETROFIT ROOF	No	POST-RETROFIT ROOF INSULATION	POST-RETROFIT ROOF INSULATION	POST-RETROFIT ROOF INSULATION	POST-RETROFIT ROOF INSULATION	POST-RETROFIT ROOF INSULATION
Ground floor insulation	PRE-RETROFIT	No	POST-RETROFIT	POST-RETROFIT	POST-RETROFIT	POST-RETROFIT	POST-RETROFIT
Shading system	No	No	No	No	Yes	No	No
Ceiling fan	No	No	No	No	No	No	No
Cooling system	No	No	No	No	No	No	No
PV system	No	No	No	No	No	No	No
Heating generation	Traditional heating system - gas boiler	Traditional heating system - gas boiler	Traditional heating system - gas boiler	Traditional heating system - gas boiler	Traditional heating system - gas boiler	Traditional heating system - gas boiler	Heat pump
Mechanical ventilation system	No mechanical ventilation	No mechanical ventilation	Facade integrated decentralized ventilation system with heat recovery	Facade integrated decentralized ventilation system with heat	No mechanical ventilation	Facade integrated decentralized ventilation system with	Facade integrated decentralized ventilation system with

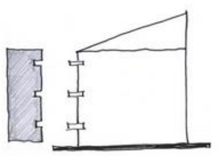
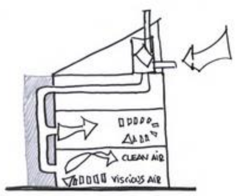
Figure 34 Results provided by the 4RinEU Rating Tool for the presets as shown in Figure 33.

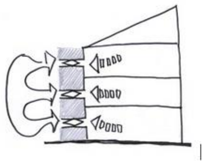
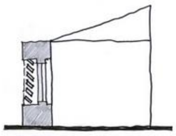
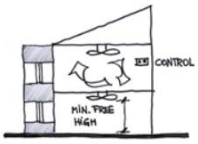
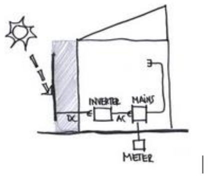
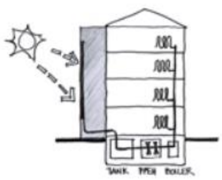
show, that a standard solution would result in the best-combined score. This would mean, with the user preferences chosen, no prefabricated façade is recommended. At the same time, the detailed results show, that the Standard renovation package also has the highest heating demand and the lowest comfort.

Application of the 4RinEU renovation packages

In Table 13 a qualitative analysis was carried out with the aim, to evaluate the applicability of 4RinEU technologies, as single parts of the 4RinEU renovation packages, to the building typology defined for the historic case study 2. (Table 13)

Table 13 Qualitative analysis of the applicability to the historic Case Study 2 of individual components from the 4RinEU solution packages from the perspective of heritage preservation

 Prefabricated Façade	In the buildings, where the façade system is recognized as valuable, an external application of a prefab façade is not possible. This applies to both facades, the entrance side and the back side because in this type of urban developments with detached block buildings the façades are exposed in the same way. – a different treatment of the two main facades is not recommended. Nevertheless, as an alternative to the demolition and new construction of representatives of that archetype, the renovation with prefab.-facades should be evaluated. A reapplication of the existing cladding system or a new interpretation can be applied. The load bearing function of the lightweight structures for the application of prefab façade elements has to be tested.
	Centralized ventilation systems aim to guarantee the proper ventilation rate within the building can be considered valuable in many cases, especially in historic buildings described here. Anyhow, the space for placing the ducts is very limited because of optimized floor plans in the social housing and additional low height of the floors. Alternatively, active overflow ventilation systems should be

Balanced AHU/HR	proofed. For central ventilation units, only the space of the storage rooms could be used.
 Façade Integrated Ventilation/HR	The parametrization of the archetype "4RinEU MFH Netherlands" results in the use of façade integrated decentralized ventilation system. But these ventilation units would be placed in the window openings what would change the existing window size. The existing slim window frames were considered of high heritage significance, therefore the application of decentralized ventilation units in the historic case study is considered critical.
 Integrated Shading	The parametrization of the 4RinEU archetype MFH Netherlands shows that the use of a shading system is resulting in a significantly lower energy demand for cooling. Therefore the integration of a shading system when applying a prefab –façade should be included in the planning options.
 Smart Ceiling Fan	In no of the best scoring options in the 4RinEU archetype MFH parametrization the use of the ceiling fan or another cooling system is recommended. Furthermore, the recommended solutions by heritage experts for this historic building typology don´t include the application of cooling systems.
 Building-integrated PV/ST	Building-integrated PV systems should not be excluded per se in a historic context. Nevertheless, the positioning of PV or solar panels must be done very carefully. Façade integrated PV systems are only possible when replacing the cladding is allowed from a conservation point. The size of the elements and the design has to be adjusted to the existing elements. Nonvisible PV systems at the roof are related to low risk from a heritage perspective.
 Energy HUB	The Energy Hub is a hydronic system able to manage complex heating and cooling system. It can be used in combination with a solar-thermal system, as well as with a heat pump and it can properly control the heat fluxes depending on the required needs. (see D3.3) Since the use of heat pumps was recommended for the refurbishment of the historic building, the Energy Hub can be used. All recommendations of the Risk management for the energy hub (see Del. 4.2) are the same for the historic case.

3.2.3 Case Study 3, Ireland: A Georgian style building in Limerick

The third case study examined in this report is the Limerick Chamber of Commerce. Unlike the other two case studies, this one was also the subject of further activities in the 4RinEU project. Specifically, it is one of the Early Adopter case studies referred to in Task 7.6 - Geo-cluster networking.

Description of the building

The building built between 1795 – 1880, is a Georgian style building originally used for apartments. Today it hosts the Chamber of Commerce with its offices. It is recognised worthy of preservation on a regional level, because of its architectural artistic value. (Figure 35)

In the National Inventory of Cultural Heritage for Ireland, the cultural significance of the building is appraised as following *"This fine structure is remarkable for the intactness of its early nineteenth-century interior which exists in sharp contrast with the later nineteenth-century stucco façade. The retention of many fine architectural elements, all well-maintained, allows the viewer to appreciate the fine Georgian internal spaces, with refined detailing adding to the restrained effect intended by its designer. The presence of the dovecote with triangular pediment over the coach house at the end of the garden is another significant object of architectural merit and provides a neat termination to the garden" [36]*.

Figure 35 The Limerick Chamber of Commerce. (Source: https://www.limerick.ie/cityxchange/dpeb-buildings/dpeb-building-2-chamber-commerce)

Figure 36 The Limerick Chamber of Commerce. Rear site enclosed from lane by an original coach house (Source National Inventory Ireland)

The Inventory provides also a comprehensive description of the Chamber of Commerce:

- Terraced house, three-bay/four-storey with basement
- Built circa 1800, refaced in stucco circa 1880
- Rusticated ground floor, cast-iron balconette giving emphasis to the piano nobile
- Roof concealed behind parapet wall to front and rear with red brick chimneystack
- Stucco rendered façade
- Segmental-arched window openings at ground floor level, one-over-one timber sash windows

- Square-headed piano nobile window openings with continuous painted stucco sill course, continental-style casement windows with fixed horizontal overlights, c. 1880.
- Square-headed second and third-floor window openings with continuous sill course at second-floor level, two-over-two timber sash windows at second-floor level and replacement uPVC windows at third-floor level.
- Rear site enclosed from lane by original coach house
- Garden elevation retaining an unusual triangular arranged red-brick dovecote flanked by oval window openings with brick surrounds.
- The interior retains much of its c. 1800 spatial arrangement and architectural detailing.
- Entrance hall with glazed inner porch screen
- Staircase hall is distinguished by decoration with architraves and pilasters and archivolts
- Entrance hall ceiling with low relief compartments
- Three-bay piano nobile room with arched inter-communicating opening to rear room, flush chimneybreast with marble chimneypiece
- The window openings retain original shutter boxes and flat-panelled timber shutters, the ceiling is decorated with a sprayed feather boss with elaborate low relief surround
- The first-floor rear room is similarly decorated.

The building is located in a closed perimeter block development of the late 19th century. The street facades are characterised by rich ornamentation. In the case of the building under consideration here, the elements of the rear façade also receive special attention, as there is still an original coach house there. However, the building does not only have elements worthy of protection in the exterior façades. The interior also contains many elements of historic features, such as stucco work, staircases, and historic doors. These have to be treated with special respect when planning renovation measures.

Heritage Significance assessment in 4RinEU project

Originally, a heritage attribute assessment was planned for the historic case study of the Limerick Chamber of Commerce according to the approach of L. Havinga. However, in addition to the heritage experts, as invited by Havinga, more stakeholders were to be invited to participate in the heritage significance assessment survey. This should have provided aspects for conservation independently of the art historical assessment. The survey was always intended as a supplement to the official assessment by the heritage office, not as a substitute. The aim was to place particular emphasis on those areas that are not characterised by art-historical and architectural values.

Due to the limited contact possibilities with the COVID-19 pandemic, however, only an initial small test with a few participants could be carried out in April 2021. The participants of the Early Adopter Workshop carried out within the 4RinEU project in April 2019, were asked to fill the template in Figure 37 This was focused on the main facade. Besides inserting some general information about their professional background and their relation to the building, they should point out attributes, which they consider significant. This was not only regarding a valuable cultural significance but also attributes that were considered as possible to be removed or changed. For the other facades or the interior, detailed interviews were no longer possible. The result of this first exercise using the front façade is shown below in Figure 38.

H2020 4RinEU

Reliable models for deep renovation

Geocluster strategic network, Workshop 1: setting the strategy The template is an initial exercise to test the approach of the attribute significance assessment. It follows the principles presented in the presentation.	
Personal Data	
Please estimate your knowledge of the building on a scale from 1 to 5:	1 2 3 4 5 1 = never seen 5 = exact knowledge
What relation do you have to the building (e.g. user, architect, neighbour, heritage authority)?	
Attribute significance assessment (building level) Take a look at the picture below. Use the colour code and mark directly in the picture all attributes, that you notice - whether positive or negative. Remember: This is not just about historic references! On the right side there is space for short explanations and notes.	High (green) – Loss is considered unacceptable, and damage should be kept to the absolute minimum Medium (blue) – Loss or damage might be considered acceptable under special circumstances Negative (red) – Loss or damage would be considered beneficial

Figure 37 Heritage attribute assessment for 4RinEU historic case study 3, Limerick. Template provided to the participants of the Early Adopter Workshops.

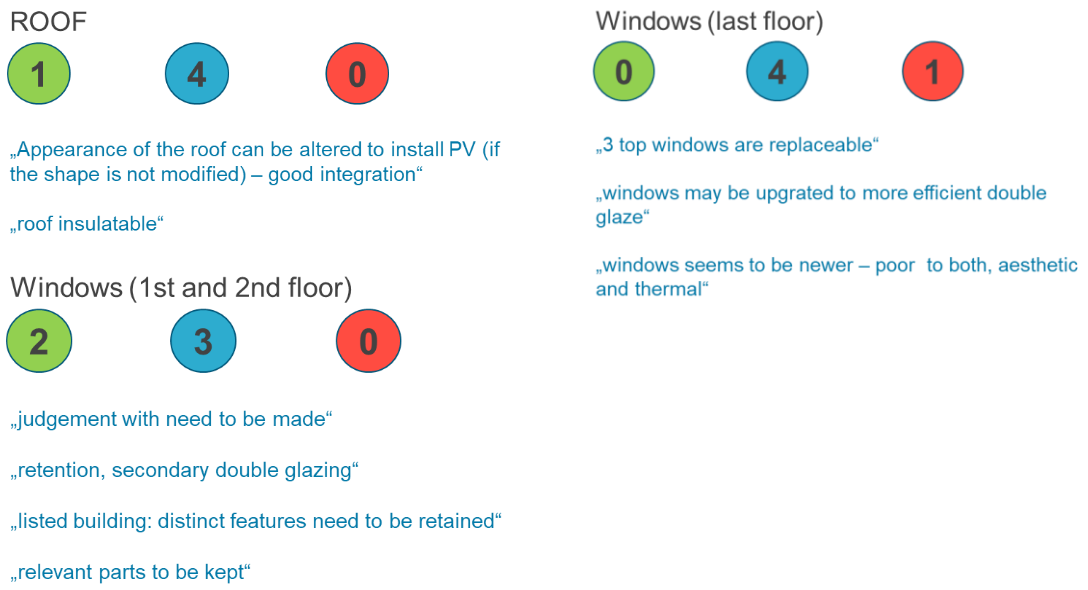


Figure 38 Results of the heritage attribute assessment for 4RinEU historic case study 3, Limerick. Examples of the street façade. The number in the colored circle refers to the number of mentioning: green=loss is considered unacceptable; blue=loss or damage might be considered acceptable; red=loss or damage would be considered beneficial.

Recommended Solution for the archetype

In the case of the Georgian House, a solution cannot be considered independently of the urban context. In the H2020 project +CityxChange, Limerick is one of the Lighthouse cities. Among other things, a positive energy block is to be brought to life in the district of Georgian Houses. The Chamber of Commerce building under consideration is also part of this block and was found to be particularly efficient in a preliminary analysis. This is certainly due less to the existing building structure and more to the dense compact urban development

Proposed measures by the +CityxChange project for the type of buildings are

- Zone heating control
- DHW supply T reduction
- Improvement of airtightness
- LED Lightning
- Boiler upgrade

And if in line with heritage requirements also following deep renovation measures were considered possible in the +CityxChange:

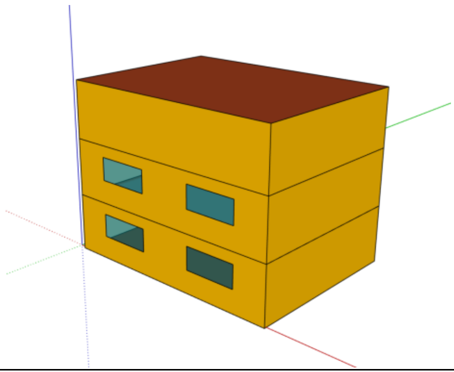
- Roof insulation
- Internal wall insulation
- Groundfloor insulation
- Windows retrofit
- Air-to-water heat pump for space heating and DHW

For the Chamber of Commerce, with these renovation measures, a reduction of 86.9% of the energy demand was assumed possible. (Source: Presentation of the +CityxChange project during the 4RinEU Early Adopter Workshop in Limerick)

According to the guideline for Energy Efficiency in Traditional Buildings in Irland 2010 [37], the assumption about possible renovation solutions for that type of buildings is not that different. One of the examples considered in the guidelines is a Georgian house. What is interesting is, that in this case study after applying draught excluders in the windows these were partly removed later to counteract the effects of excessive heat given off by electrical office equipment. The installation of a heating distribution system with radiators was rejected in favour of high-efficient electrical storage heaters with convector fans because the pipework for radiator systems would have a high impact on the building fabric. This would be also to be considered in the Chamber of Commerce because the interior decoration also here was valued as worthy of preservation. In the guidelines also a roof insulation was recommended and the application of PV at the roof was seen possible.

Use of 4RinEU technologies

Because the Chamber of Commerce in Limerick was one of the 4RinEU Early Adopter case studies, a further 4RinEU Archetype was created in the Rating Tool for the specific case: a 3-story-height building where East and West orientation have been considered adiabatic, in order to recreate the adjacency condition (Figure 39). The related parameterizations were carried out for the different 4RinEU solution packages. All simulation results and further explanations are accessible in 4RinEU Deliverable 4.4.



N° Floors= 3

Area per Floor= 75 m²

Building Height= 7.5 m

Building Width= 7.5 m

Building Length= 10 m

EXISTING WALL U-value = 1.62 W/m²K

(E/W sides: ADIABATIC)

Figure 39 Archetype defined according to the Early Adopter case study in Limerick (Source: 4RinEU project, Del. 4.4)

Some of the anyway-measures (measures considered in the calculations, that are no 4RinEU technologies, which should be applied) considered for the simulations of the case studies in 4RinEU Task 2.1 are the same as the recommended ones for the historic building stock in the guidelines mentioned above – here the one in Limerick.

- The improvement of heating system efficiency,
- The presence of a cooling system (in case it is needed)
- The retrofit of windows
- The reduction of infiltration rate, assuming to have an airtight building after the retrofit
- The roof and ground floor retrofit, assuming an improved insulation level.

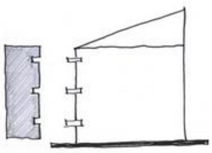
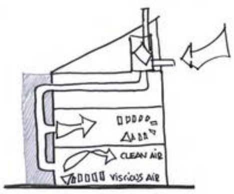
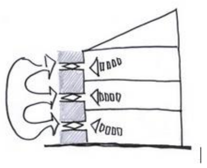
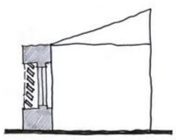
As in the historic case studies 1 and 2 described in the report here, conflicts occur mainly with the application of the prefabricated façade. In the simulation results shown in Deliverable 4.4 one can see, that the application of the prefabricated façade leads to the highest reduction of the energy demand. The comparison with other intervention possibilities of insulation, like internal insulation was not assessed. Anyhow, even without any insulation of the facades, only applying the standard measures as mentioned above, brings a reduction of 45%.

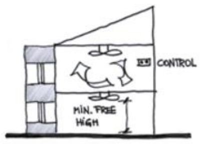
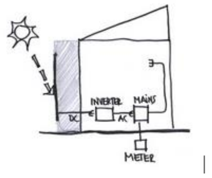
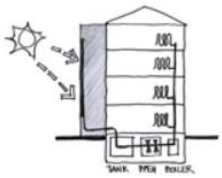
Note: In the guidelines Energy Efficiency in Traditional Buildings is stated, that the calculation of the energy demand in historic brick buildings is difficult since the U-Value of a traditional brick wall is not defined. Only measured data could bring trustable results. The BuildDesk U 3.4 calculator gives values of 0.77 W/mK and 0.56 W/mK respectively, and Everett (1986) and CIBSE (2006) provide a wide range of values based upon the different densities and moisture contents of brick [37].

Application of the 4RinEU renovation packages

In Table 14 a qualitative analysis was carried out for the Chamber of Commerce in Limerick with the aim, to evaluate the applicability of 4RinEU technologies, as single parts of the 4RinEU renovation packages, to the building typology defined for the historic case study 3. (Table 13)

Table 14 Qualitative analysis of the applicability of individual components from the 4RinEU solution packages to the historic Case Study 3 from the perspective of heritage preservation.

 Prefabricated Façade	In general not possible due to the protection of the façade and the limits regarding the overhang to the public space (pedestrian). In some exemptions, an application in the backyard can be considered, but due to irregular facades and only limited area, the replication potential of prefabricated solutions is very low. In the Limerick Chamber of Commerce case study, parts of the rear façade also include some significant attributes with the red brick dovecote.
 Balanced AHU/HR	Because the building is used as office space, a centralized ventilation should be taken into consideration. Anyhow special attention has to be paid to the placement of the ducts because of the existence of decorated ceilings etc. For the vertical distribution usually, the existence of chimneys etc. can be used, so there is no need for putting it to an exterior façade element. The bulky machines usually can be placed in the attic or attached buildings.
 Façade Integrated Ventilation/HR	A façade integrated decentralized ventilation system as foreseen in the 4RinEU package will not be suitable for the archetype considered here. As the ventilation units are placed in the window opening this would change the existing window size. Even in case of the replacement of existing windows (because of poor performance and low heritage value) a change of the window size would not be considered feasible.
 Integrated Shading	The window openings retain original shutter boxes and flat-panelled timber shutters. Where historic shading systems still exist, these should be reused or in case of destruction, a new shading system should take examples of the historic one.

 Smart Ceiling Fan	Some of the ceilings are decorated with a sprayed feather boss with elaborate low relief surround. The application of the fans would therefore be difficult. The need of a cooling system in the Northern Geo-cluster is discussed elsewhere and depends also on the used technical equipment in the rooms.
 Building-integrated PV/ST	Building-integrated PV systems should not be excluded per se also in a historic context. As an example, they can serve the integration of PV panels in Edinburgh in the World Heritage site. Nevertheless, the positioning has to be done very carefully – non-visible surfaces or outbuildings can be taken into consideration. However, these remain exceptions and can only be decided on a case-by-case basis.
 Energy HUB	The Energy Hub is a hydronic system able to manage complex heating and cooling system. It can be used in combination with a solar-thermal system, as well as with a heat pump and it can properly control the heat fluxes depending on the required needs. (see D3.3) The Energy hub can be used independently from the prefabricated façade.

4 Conclusion

It has been shown that the 4RinEU technologies can only be used to a very limited extent for historic buildings. The major advantages, such as reduction of construction time, cost efficiency and robustness, cannot be demonstrated in historic buildings. It is certainly worth examining the use of individual elements, such as the ceiling fan, the energy hub, etc., in the refurbishment of historic buildings - and in one place or another the technology will also turn out to be the most suitable. However, there can be no generalisation for the following reasons:

Prefabricated façades: In most cases, it is not possible to integrate the façade at all, as it is not permissible to change the exterior view. Reasons for restriction can be related to the protection of cultural values of the historic appearance of the façade but also related to building regulations. Particularly in the renovation of Wilhelminian-style districts with courtyards, it is sometimes possible to attach the façade to the courtyard side, because here the visual impact is considered acceptable and also the conflicts attaching the overhang into the public space does not exist usually. However, considerations must be given to the existing, usually inhomogeneous façade structures. The potentials of prefabrication, away from the building site, but possible to mount in a very short time, are not of advantage for that building types. However, solutions that can be adapted to the existing irregular structure on the building site have proven to be suitable. Furthermore, the share of possible exterior insulation with curtain walling in the overall renovation package would only be possible to few façade areas, thus, the associated planning effort would not be economical.

In addition to these technical problems, it has also become apparent that the historic building typologies for which the 4RinEU technologies were tested represent a too small and inhomogeneous group of buildings to be relevant for the application of the 4RinEU technologies and methods. However, the chosen historic Archetypes are relevant in the overall stock of historic heritage. Probably the largest historic building typology in Europe - across the different Geo-clusters - is the Wilhelminian/Victorian building style, i.e. the urban extensions of the industrialisation in the second half of the 19th century until the beginning of the 20th century. These buildings typically were built in perimeter blocks, about 4 storeys high and with 6-8 residential units (depending on the city) and often with additional buildings in the courtyards. These buildings usually consist of solid brick walls (plastered or untreated) and wooden slide-in ceilings. Two buildings belonging to this group in a wider sense have been included as case studies in the above considerations: C1 and C3. In both cases, it has been shown that the application of the 4RinEU packages is only possible to a limited extent and that the transfer is also difficult.

It can be summarised that individual technological and methodological developments from the 4RinEU package can be applicable in individual cases. In a decision-making process for the deep renovation of a historic building, as described in EN 16883, these technologies will only be one out of a long list of alternatives.

It has been shown in many respects that it is not possible to implement standard solutions in historical buildings, because of the diversity of the building stock. The decisions have to be made on a case-by-case basis. This requires a detailed planning approach, with the necessity to involve a whole range of experts. Another reason for the impossibility of providing standard solution in the methodological approach is ownership structure in historic housing because is of great diversity and has grown historically - unlike perhaps the case in the social housing of the 1970s.

The example in the Netherlands, as part of a mass housing project with a panelled lightweight construction, initially seems like an ideal case for the application of the prefabricated façade. Nevertheless, the analysis of this example has also shown that this cannot be assumed without reservation. In the case of historic buildings in lightweight construction, the precise adaptation of the façade is particularly important: statics, proportions, façade division and rhythm, as well as the surface materiality. The effectiveness of such "special production" was not investigated within the 4RinEU project.

The study was able to show that individual technological and methodological innovations developed in research projects such as 4RinEU for the younger building stock can certainly also be considered for application in the historical stock. However, it was also pointed out that the historic building stock requires a fundamentally different approach than the one used as a basis in the 4RinEU project. This approach for historic buildings is based on a case-by-case consideration that carefully takes into account the historical values and involves experts for detailed planning.

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