FuturHist

Building typology: analysis of the building stock and typologies definition

Project Overview

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Executive Summary

Futureproofing historic buildings on a large scale is an ambitious target: carbon neutrality goals call for quick actions; instead, the energy retrofitting of historic buildings requires complex planning to optimize the energy savings with the preservation of cultural value. FuturHist aims to develop typology-based strategies to boost the futureproofing of buildings erected before 1945. Typology-based strategies can enhance the potential of existing tools for the energy retrofitting of historic buildings because they link retrofit solutions to specific building typologies – rather than only to specific buildings or building components. However, a comprehensive methodology to define historic building typologies needs to be defined to close the gap between building typologies based on statistical average quantitative data and the characterisation of historic buildings based on isolated example.

This task focuses on the definition of the building typologies that are used in FuturHist and on the quantification of their energy performance. First, a methodology to define historic building typologies is developed to characterise historic buildings considering general information, geometric parameters, architectural characteristics and heritage elements to be preserved. Second, the methodology is applied to define nine typologies of historic buildings located in Spain, Poland, Sweden and UK. Third, the energy performance of the defined typologies is quantified considering U-values of building envelope components and energy demand and consumption for heating and cooling.

The results of this task show that it is possible to apply a typology-based characterisation to historic buildings. However, the features selected to define the typologies only refer to the original configuration of the buildings. For this reason, a series of variable features complements the characterisation, providing information about the most typical current situation of the buildings belonging to a defined typology. The energy performance of the typologies has been quantified generating ranges of values. This strategy takes into account the variability of building materials and construction techniques of historic buildings.

The typologies defined in this task include the ones of the demonstrator buildings (for which retrofitting solutions will be developed in WP2 and WP3 and tested in WP5) and the ones to be used for the replication phase in WP6. Furthermore, the features identified to define typologies, as well as the range-based method to quantify the energy performance of historic building typologies constitute inputs for WP4.

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Disclaimer

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Abbreviations and definitions

Archetype building	Theoretically defined building based on the typical or average census values (Berg, 2015).
Authenticity	Grade of preservation of original state of a property in terms of function and use, form and materials, and environment (Code wallon du Patrimoine, 2023).
Building envelope	The “skin” of a building, consisting of exterior facing walls, roof, windows, and lower floor slab.
Building typology	A set of buildings with common properties (e.g. age of construction, geometry, thermo-physical properties, and energy performance) (IEE Project TABULA, 2012).
Demonstrator building	A real building belonging to a typology which is used to demonstrate retrofitting solutions (also referred to as “demo case” - DC).
DHW	Domestic Hot Water, i.e., heating water for domestic or commercial purposes other than space heating and process requirements (ASHRAE, 2024).
Energy consumption for heating and cooling	Energy input required to satisfy the heating and cooling demand of a building. This quantity considers also efficiency and losses of systems and user behaviour (Hotmaps, 2020).
Energy demand for heating and cooling	Calculated amount of energy required to cover heating and cooling of a building (Hotmaps, 2020).
Energy retrofit	A general concept for all types of renovations where reduced energy consumption is the main goal for the renovation (Eriksson, 2021). It is used for the entire renovation process, from planning to evaluation, and is closely related to sustainable renovation (Thuvander et al., 2012). Sustainable renovation of existing buildings is a way of extending the lifespan of a building and improving its living and working conditions, which includes lowering the energy used for those purposes (Asdrubali and Desideri, 2018, chapter 9).
EPC	Energy Performance Certificate.
EU	European Union.
Floor area (of a building)	Area of the floor surface of indoor spaces of a building.
Footprint (of a building)	The border of a building drawn along the exterior walls, to create a polygon, representing the total area of the building.
Heritage value	Aspect of importance that individuals or society assign(s) to a building (EN 16883:2017). Note 1 to entry: Heritage values can be of aesthetic, historic,

	scientific, cultural, social or spiritual nature. These types of heritage values include various aspects, for example: architectural, artistic, economic, symbolic, technological, use, etc. Note 2 to entry: The heritage assigned value can change according to circumstance, e.g. how the judgement is made, the context and the moment in time. Value should always be indicated by its qualifying type.
Historic building (HB)	Building of heritage significance (EN 16883:2011) Note 1 to entry: A historic building does not necessarily have to be statutorily designated as cultural heritage. Note 2 to entry: Historic buildings are a specific form of objects, as defined in EN 15898:2011, 3.1.3.
HVAC	Heating, ventilation, and air conditioning
Integrity	Grade of homogeneity and coherence of a property in terms of physical integrity of the building. This criterion evaluates the condition of the building compared to what it was at the time of its construction, from the point of view of the physical composition of the materials and the construction techniques of the building period (Code wallon du Patrimoine, 2023).
KPI	Key performance indicator.
PMV	Predicted mean vote.
PPD	Predicted percentage of dissatisfied.
Rarity	Grade of uniqueness of a property in terms of typology, style, dating, or interest, whether social or historic (Code wallon du Patrimoine, 2023).
Reference building	Actual building designated to represent a building stock by data obtained from statistics or surveys, with the condition that the sample size is sufficiently large (Berg, 2015). FuturHist demonstrator buildings are reference buildings within their respective typologies.
Representativeness	Grade of preservation of property’s architectural characteristics linked to a specific function (Code wallon du Patrimoine, 2023).
U-value	Thermal transmittance value, i.e., the rate of transfer of heat through a structure.
WP	Work Package.
WWR	Window-to-wall ratio.

1. Introduction

1.1. Background and objectives

Within the framework of the ambitious targets of the European Union (EU) for achieving climate neutrality by 2050, FuturHist aims to boost the futureproofing of historic buildings by tackling the paradox of applying standardised approaches to a significantly heterogeneous and culturally valuable part of the EU building stock. Historic buildings were mostly erected before the implementation of contemporary industrialized construction methods, standardized building components and energy-saving design guidelines. For this reason, their material and architectural qualities represent the diversity of climates, the difference in the availability of resources and the evolution of local cultural contexts during the past centuries. In addition to that, the positive acknowledgement of their representative cultural value (at national and/or international level) promotes the preservation of their heritage features by further limiting the possibility of their alteration.

Effective solutions have already been tried and tested to improve the energy performance of listed and non-listed historic buildings while preserving their heritage features. Successful experiences demonstrated that tailored approaches developed for specific buildings achieve optimization between the energy efficiency and the heritage value preservation (Eriksson & Johansson, 2021; Herrera-Avellanosa et al., 2024; Stiernon et al., 2017). However, the development of effective tailored approaches also proved to be more demanding in terms of time and effort compared to the implementation of standardized solutions that are suitable for non-historic buildings (Nair et al., 2022). The increased time and effort required make the process of energy retrofitting of historic buildings very time consuming and complex to be applied systematically on a large scale by 2050. Thus, limiting the role that can be played by the oldest part of the building stock part of the building stock within the quest for decarbonization. In fact, timing is essential for addressing the European decarbonisation targets. For this reason, a solution for accelerating the design process of energy retrofitting of historic buildings is needed.

Successful retrofit experiences have shown that it is not possible to implement standardized retrofitting approaches in historic buildings. However, previous research projects have produced valuable tools to collect and share information about tried and tested retrofitting solutions for specific historic building components. These resources include written guidelines for retrofitting (Association Ajena, 2022; Blumberga & de Place Hansen, 2020; Leijonhufvud et al., 2021) as well as interactive digital tools (e.g., HiBERtool, RIBuild Insulation calculator tool, OPERA) to facilitate the decision-making process for retrofitting certain building components of historic buildings.

FuturHist can enhance the potential of this type of tools by linking retrofit solutions and strategies to specific building typologies – rather than only to specific buildings or building components – thus accelerating the retrofitting design phase. For this reason, the identification of building typologies is essential for the development of this research project.

Building typologies are sets of buildings with common properties (e.g. age, size, geometry, thermo-physical parameters and energy performance). The concept of building typology has been already effectively implemented for the analysis of the European building stock (BSO, 2024; Moderate, 2022-ongoing, Hotmaps, 2020) and for the assessment of its renovation potential (Birchall et al., 2014; Nemry & Uihlein, 2008; Ortega et al., 2022; Pascual et al., 2015; Pinotti & Pernetti, 2021). These works do not deal with valuable historic building stock; therefore, they do not approach the definition of typologies considering the diversity and the heritage features of buildings realized before 1945. The definition of historic building typologies requires the implementation of a more complex categorisation approach.

The main objective of this task is to define the nine building typologies that are used in the project and quantify their energy performance. The buildings selected as demonstrators for FuturHist constitute the starting point for identifying the set of features used to define typologies within this project. The demonstrators are historic buildings located in Spain, Poland, Sweden and UK. The investigation of the context of each case provides the framework to assess their relevance and representativeness within their national building stock. Existing databases, literature, on-site survey and archival sources, plus the monitoring of the real buildings used as demonstrator in the project, provide the necessary data to identify the ranges of their energy performance.

The typologies defined in this task are needed for the implementation of different interconnected FuturHist WPs. First, five typologies are defined in this task starting from the five real buildings selected to be used as demonstrators. That is to ensure that the retrofit solutions developed in WP2 and WP3, and tested in WP5, are linked to the typological features of each demonstrator building – and not limited to the building-specific parameters. Second, the features identified to define these typologies are used to tailor the integrated planning toolkit implemented in WP4. Third, additional four typologies are characterised in this task, based on the features used to define the typologies of the demonstrator buildings. These additional typologies will be used in WP6 for the validation of the guideline elaborated for the replication of the typology-based approach.

1.2. Organization of this report

Section 2 of this report includes the description of the methodology implemented for the main three steps of this task: (1) the definition of the typologies, (2) their contextualization at national level and (3) the quantification of their energy performance.

Section 3 presents and discusses obtained results. First, the features selected to define typologies in this project are described and argued. Second, the nine defined typologies are presented by country, focusing on: their typological features, their representativeness within national building stock and their energy performance. Third, the potential applications and the limitations of the results are presented.

The conclusion summarizes the main outcomes of this task and links them to the next steps of the project.

2. Methodology

Both qualitative and quantitative research approaches have been implemented for the development of this task. The following subsections provide the description of the methodology adopted to carry out each step of this task.

2.1. Defining the typologies

Literature review has been the preliminary step taken before approaching the definition of the typologies within this research project. The references collected provided a robust knowledge of how typologies have been defined and implemented in previous research linked to building energy retrofit. This knowledge was crucial to assess the potential and the limitations of the typology-based approaches. Furthermore, the literature review also provided a common set of definitions used within this task (these definitions are included in the glossary at the beginning of this deliverable.)

Once clarified the scope of the use of typologies within the targets of this research project, the following method was implemented to define them. Since the project includes the demonstration of retrofitting solutions on real buildings, it was essential to define the typologies to which the buildings used as demonstrators belong to. Therefore, an extensive list of building features was drawn up and used to set up data collection sheets to collect information about the demonstrator buildings. The list of features was obtained combining the features used in the framework of previous research dealing with typologies in relation to energy performance categorisation of building stock (Berg, 2015; Birchall et al., 2014; Bourru & Burgholzer, 2011; Dahlström et al., 2024; Haas et al., 2021; Nemry & Uihlein, 2008; Typology Approach for Building Stock Energy Assessment, 2012) and energy retrofit of heritage buildings (Association Ajena, 2022; EFFESUS consortium, 2016; Janvier et al., 2011; Leijonhufvud et al., 2021; Pascual et al., 2015; Stiernon et al., 2017).

The data collection sheets have been organized in 4 different sections, referring to different categories of building features:

1. General information (13 features)
2. Energy behaviour (31 features)
3. Building configuration (12 features)
4. Cultural values (15 features)

Using literature, archive material and field studies, the partners who proposed the five demonstrator buildings have filled in one data collection sheet for each demonstrator building. The complete data collection sheets provided detailed information about each of the demonstrator cases, which also serve as basis for the development of WP2, WP3 and WP5.

Comparing the information collected on the demonstrator buildings, it was possible to select the features that differentiate historic building typologies from one another. The selection was made to provide an intermediate set of features that stands between the extensive list of features necessary to define a real building and the fewer categories implemented to define typologies within the main research projects based on this approach at the European level (BSO, 2024; Moderate, 2022-ongoing, Hotmaps, 2020; IEE Project TABULA 2009-2012).

Based on the selected features, the typologies to which the five demonstrator buildings belong to were described. Then, the process of selecting another four typologies was also performed to validate the effectiveness of the selected defining features. Without using a real building as a starting point, the partners responsible for the demonstrator buildings described four other typologies (one for each country in which the demonstrator buildings are located) according to the given features. This operation helped refine the list of defining features by removing redundant elements.

2.2. Contextualizing the defined typologies

The five buildings to be used as demonstrators as well as the additional typologies to be used for further theoretical application within the FuturHist projects have been selected by the local partners based on their historic relevance. An overview of the socio-economic factors that determined the development of each of these typologies allows to contextualize them at their national level and claim their historic relevance.

Furthermore, existing datasets containing quantitative data about the typologies of building stock in European countries (BSO, 2024; Moderate, 2022-ongoing, Hotmaps, 2020) provided the quantitative basis to assess the representativeness of each typology at national level. When available, the results of national surveys contributed to deepening the understanding of the diffusion of each typology at local level. Quantitative assessment of the representativeness of each typology is completed by a qualitative overview of their diffusion at national scale in relation to historic changes and technological developments of the building sector.

2.3 Quantifying the energy performance of the defined typologies

2.3.1. Generating energy performance ranges

The process of quantification of the energy performance of the defined typologies included quantification of thermal transmittance (U-value) of the components of the building envelope (wall, roof, floor and windows) as well as the quantification of the energy demand and energy consumption for indoor thermal comfort (heating and cooling).

Initially, existing datasets and tools providing statistical quantitative data about the building stock in European countries and in the U.K. (BSO, 2024; Moderate, 2022-ongoing; Hotmaps, 2020) were examined to extract information about typical construction materials, construction methods and U-values of building components, as well as about statistical typical energy demand and consumption for heating and cooling. Extracted data provided an overview of the average performance of buildings by country, age, sector (residential or service), and building type (single family houses, multifamily houses, apartment blocks, offices, trade, education, health, hotels, other non-residential buildings).

These categories are applied in the datasets to all the building stock; instead, the classification by period of construction is not consistent. Buildings erected after 1945 are categorized in BSO, Moderate and Hotmaps by construction period ranges of 10 years (from 1970) and of 35 years (1946-1969); instead, all buildings erected before 1945 are considered within one single age class. This classification is meant to provide average information about the performance of the eldest part of the European building stock, as a simplified group. For this reason, the information extracted from the aforementioned datasets has been complemented with data from other sources to verify and/or increase the accuracy of the performance quantification process.

Databases, webtools and literature have been also examined to look for data about the performance of buildings which have features in common with the typologies defined in FuturHist. Sources providing statistical data about European building stock by type and location (TABULA, 2012; iNSPiRE, 2014) have been used to extract data for different typologies. In addition, further statistical data was extracted from national sources (Boverket, 2007; Boverket, 2010; Instituto Valenciano de la Edificación, 2016).

For some of the typologies defined in FuturHist and/or for their specific construction features, literature provided additional measured (Dahlström, 2024; Purcell, 2024) and calculated (Napier, 2018) data about energy performance of similar buildings (or building typologies) to enhance the accuracy of the quantification. HIBERAtlas was also examined to identify pre-interventions data representing the performance of buildings sharing similarities with the defined typologies.

The following material parameters were used as criteria to extract data from additional sources about the performance of the building components: location, age, materials and methods used for the construction of walls, roofs, floors and windows. Instead, building sector, function and geometry have been considered together with building age and location to extract data about typical energy demand and consumption for heating and cooling.

For the typologies corresponding to the demonstrator buildings of FuturHist, calculated or measured energy performance of the real buildings (when available) has also been considered for the quantification of the energy performance of the corresponding typology. For the Swedish typologies, data from EPCs of real buildings was collected by Tim Johansson at RISE Research Institutes of Sweden and used to improve accuracy.

Since walls constitute the most variable elements of buildings constructed before 1945 at national levels, a calculation of the U-values of walls based on the description of the material properties of each typology was performed with the software ProKlimaHaus (version 2022) to provide one additional entry for each typology. This method has also been applied to other elements when a significant difference compared to standards of the time and country was identified. Furthermore, U-values retrieved within the RIBuild project (2020) for different wall types of European historic buildings and U-values measured by Eurac Research in historic buildings with stone walls (Troi, 2023) have been considered for assessing the performance of the walls of each typology.

Due to the heterogenous nature of each construction technology identified for the typologies, ranges of U-Values and energy demand and consumption values rather than average values have been chosen to quantify the performance of each typology. These ranges have been generated for each typology considering the lowest and the highest values retrieved/calculated that best match the features of each typology.

2.3.2. Monitoring of the demonstrator buildings

Onsite measurements of the actual conditions and energy consumption at the demonstrator buildings will provide additional data and potentially improve the quantification of the typologies' performance, providing a robust baseline for subsequent calculations. The data collected will be for instance of use when calibrating the simulation models for the analysis of sustainable (internal) insulation systems for the envelope's retrofit in Task 2.4 or the ex-ante calculations of the different demo cases in WP5.

As part of this task, a common monitoring plan was laid out and, where possible, the first monitoring data was collected. The monitoring plan for all 5 demo cases is detailed below in terms of type of information collected, equipment used, and the expected timeframe for implementation and data collection. Additionally, data already available is briefly summarised.

Parameters monitored

- **External weather conditions**. To evaluate the data gathered at the different demo cases is crucial to know the external weather conditions at the building location. As a general approach, it was agreed to use public weather station. In those cases where the data is not available or the location is too distant, a dedicated station will be installed in the vicinity of the demo.

- **Indoor environmental quality**. The solutions developed in FuturHist, both passive and active, will have a strong focus on the improvement of living conditions. Reducing the thermal transmittance of walls and windows, does not only reduce energy losses but eliminates low surface temperatures that are known sources of indoor discomfort – improving thermal comfort as a result. Solutions will also contribute to better indoor environment with the enhanced properties of moisture buffering potential developed in WP2. On the other hand, reducing uncontrolled air leakage might have a negative effect on the air quality that should be evaluated. The integration with passive ventilation and HVAC strategies will also ensure a healthy environment and avoid the concentration of indoor pollutants and improved conditions in dwellings that were previously lacking heating and cooling services respectively. All the improvements will be accurately quantified thanks to the KPIs developed in WP1 and the data gathered from the demo cases before and after the intervention.

- **Energy use**. One of the main targets of the project is the reduction of energy demand in historic buildings by at least 60%. The quantification of potential savings will rely heavily on calculations. However, to ensure the robustness of these calculations, measured data of actual energy consumption in the different demos will be used where relevant. The nature of the data, and as such the way in which it will be used in the project, will vary among the different demos. The use of any monitoring system already in place was favoured or, alternatively, the collection of energy use data from the utility provider.

- **Moisture in construction**. Several solutions developed within FuturHist will rely on an efficient management of moisture to reduce the water absorption of critical element of the building envelope or regulate the moisture in the indoor environment. In both cases the moisture content of the building element is a good indicator; in the first case it should remain low and rather constant whereas in the second it would vary as function of the humidity in the environment. The effectiveness of the developed solutions will thus be assessed based on moisture content data measured on site.

Table 1 and Table 2 summarise the minimum requirements for the monitoring of the parameters listed above and details regarding the implementation in the different demo cases respectively.

Table 1. Minimum requirements for the selected monitoring parameters.

Category	Value	Unit	Resolution	Accuracy	Duration
External weather conditons	Temperature	°C	Hourly	NA	01.01.25-31.12.27
	Relative Humidity	%			
	Wind speed	m/s			
	Wind direction	Degree			
	Precipitation	mm			
	Solar radiation	W/m2			
	Pressure	Pa			
Indoor Environmental Quality	Temperature	°C	Hourly	±0.5 °C	01.01.25-31.12.27
	Relative Humidity	%	Hourly	±3%	
	Pressure	Pa	Hourly	±0.6hPa	
	VOC	μg/m^3	Hourly	20μg/m^3+15%	
	PM_1	μg/m^3	Hourly	±5μg/m^3+15%	
	PM_{25}	μg/m^3	Hourly	±5 μg/m^3	
	CO_2	ppm	Hourly	±50 ppm ±5%	
	Light	%	Hourly	NA	
Energy use	Total energy use	kWh/m^{2}y	Monthly	NA	01.01.25-31.12.27
Moisture in construction	Electrical resistance	%/WME	Hourly	NA	Case by case basis

Table 2. Monitoring of demo cases.

Demo case	Weather	IEQ	Energy	Moisture
DC1 – Spain, Cordoba (Plaza Corredera)	Nearby public weather station	AirThings Space Pro	NA	Scanntronik Material Moisture Gigamodule
DC2 – Poland, Krakow (Kamienica in Kościuszki Street)	Public weather station + local measurements of temperature and humidiy	AirThings Space Pro	Utility bills	Scanntronik Material Moisture Gigamodule
DC3 – Sweden, Linköping (Domkapitelhuset)	Nearby public weather station	AirThings Space Pro	From provider (electricity, heating)	NA
DC4 – Scotland, Edimburgh (SVR Lodge)	Nearby public weather station	NA	NA	OmniSense S-11 T,RH,WME
DC5 – Scotland, Edimburgh (Lister Flat in Tenement)	Nearby public weather station	AirThings Space Pro	Utility bills	NA

Interim results

- **External weather conditions**. Data accessibility has been confirmed to weather stations in Cordoba (SP), Linköping (SE), and Edinburgh (UK). Figure 1 shows the hourly values of air temperature in Cordoba and Linköping demonstrating the different weather conditions found at the FuturHist demos.

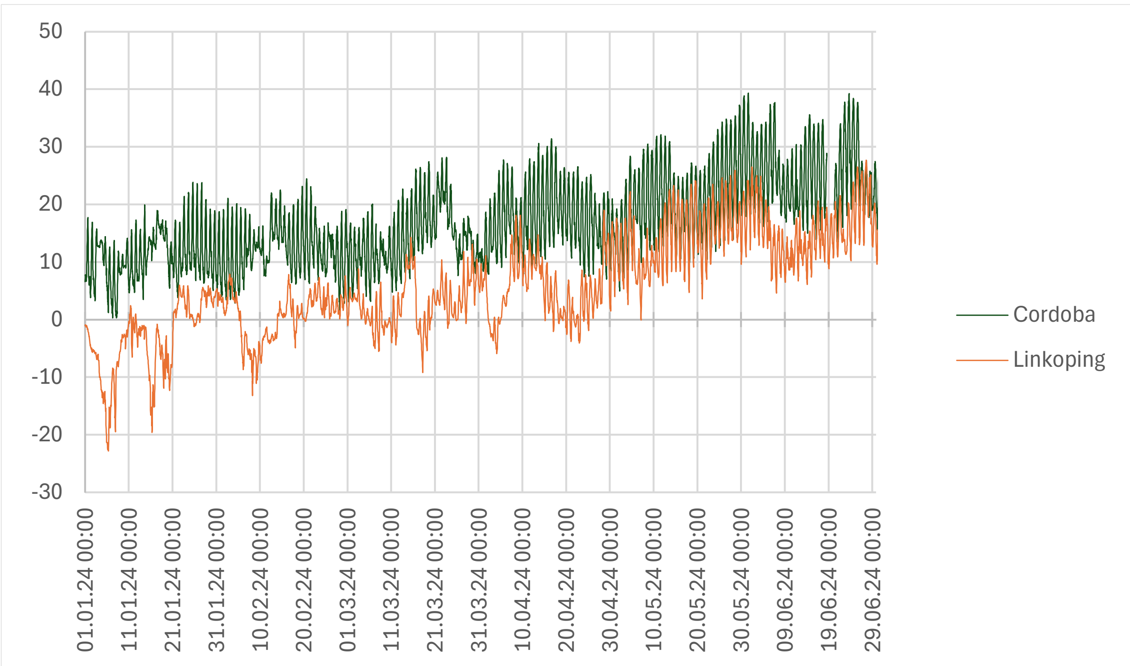


Figure 1. Hourly air temperature in Cordoba (Spain) and Linköping (Sweden) from 01.01.2024 to 30.06.2024

- **Indoor Environmental Quality**. Monitoring plans have been produced but the installation of the sensors is planned only for the beginning of 2025. In the meantime, previous monitored data from a similar case study in Spain has been consulted (Caro Martínez, 2022) and a preliminary study has been conducted at the demo case in Poland to assess the thermal comfort of two rooms (ground floor shops) based on measurements of temperature, relative humidity, and air velocity from the 11th to the 30th of April 2024. The thermal comfort tests conducted in both rooms showed significant differences in thermal conditions, largely influenced by differences in building insulation and materials. In the antique shop, air temperature fluctuated significantly, ranging from 22°C to 17.5°C. This variability was primarily attributed to the measuring point's proximity to a poorly insulated, leaky window. In contrast, the second unoccupied shop displayed far more stable temperatures, fluctuating only slightly between 19°C and just over 20°C. This stability was aided by the installation of airtight, triple-glazed windows and the high thermal capacity of the brick walls. The impact of air temperature on thermal comfort was reflected in the PMV index. In the antique shop, the index ranged widely, from -0.8 to +0.1, with most values clustering around -0.6, indicating moderate discomfort. Meanwhile, the unoccupied shop’s index remained within a narrower band, between -0.2 and -0.4, suggesting a more consistent and comfortable environment. Calculated PPD index further underscored these differences. In the first shop, 20% of people would be dissatisfied with the thermal conditions, whereas in the second shop, dissatisfaction remained consistently low at just 6%. These findings emphasize the critical role of the building envelope (thermal resistance and airtightness) in achieving thermal comfort. Additionally, the thermal capacity of surrounding materials, like brick, further contribute to maintaining stable indoor conditions.

- **Energy use**. As mentioned above, actual energy consumption data is being collected from the utility providers (or tenants where possible). As an example, Figure 2 shows a snapshot of the energy use for electricity and heating from the demo case in Sweden in the first half of 2024.

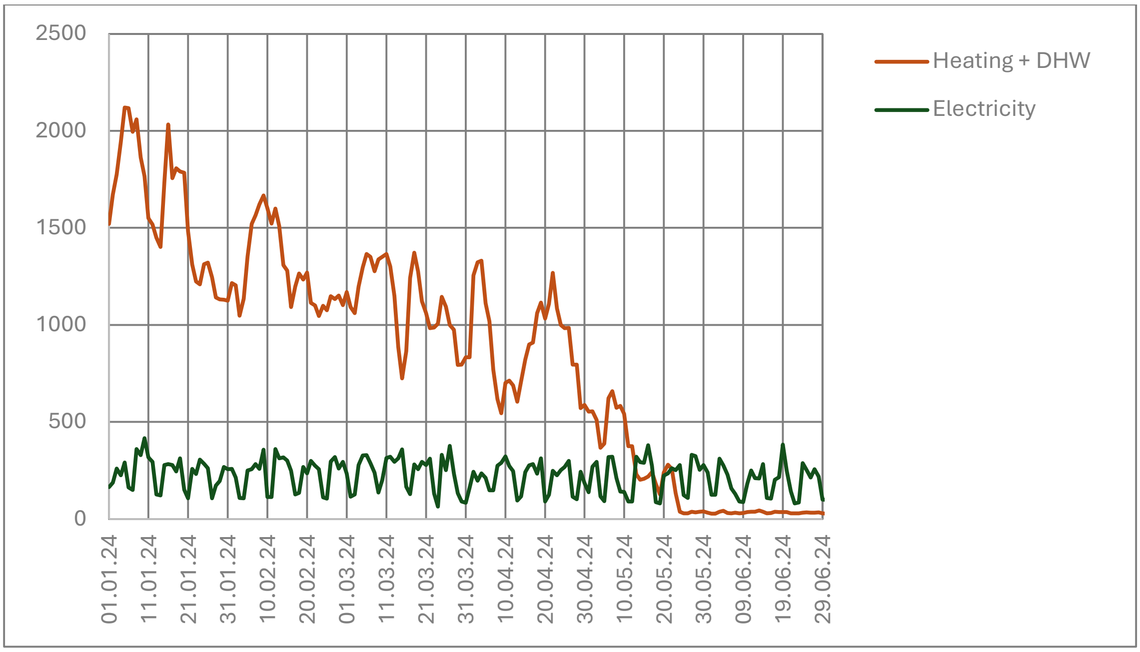


Figure 2. Daily energy consumption (kWh) for heating + DHW and electricity at DC3 – Linköping (Sweden)

- **Moisture in construction**. Prior to the installation of the monitoring system that will allow a longitudinal study of the conditions at the demo cases, a preliminary test was conducted at the polish demo case to assess the current conditions of the walls on the ground floor. Non-destructive moisture content measurements were conducted on the 5th of June 2024 using a Testo 616 meter. The instrument measures the electrical capacitance of a material and relies on predefined calibration curves to provide a result of moisture content as percentage of water in relation to the dry mass of the material. The moisture content was measured at 10 different locations at the ground floor shop and only on the sections of the walls from which the plaster was removed. The measuring probes were always placed directly on the brick, not in the joints. The results shown in Table 3 indicate that a poor condition and require meticulous diagnostic testing. This room is in the process of drying after intense flooding, so a significant amount of crystallized salts in the pores of bricks and mortar is to be expected affecting the readings. Further measurements should be repeated regularly to monitor the evolution of the moisture content in the building.

Table 3. Moisture content (in %) measurements in 10 positions and different heights at the DC2 - Poland

Mass moisture content of masonry in individual profiles [%]										
Profile	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2.5 m								12.9	1.6	
2.1 m								15.9	1.4	
1.7 m								15.8	1.1	
1.3 m	5.9	2.8	3.4	2.5	0.3	0.3	2.5	6.8	2.7	4.4
1.0 m	15.2	4.5	1.5	3.2	2.3	0.3	2.9	9.8	0.2	6.2
0.7 m	10.7	3.9	2.3	12.2	2.6	0.4	3.2	8.3	0.5	8.7
0.4 m	15.9	4.7	13.5	14.9	4.4	0.7	5.6	8.3	0.5	14.5
0.1 m	19.5	5.8	18.7	11.9	6.1	0.9	8.2	17.5	6.6	16.0

3. Results and Discussion

3.1. Features selected to describe the typologies of historic buildings

The first result of this task was the identification of a set of features to describe the typologies of historic buildings used in the project.

Previous research projects for the analysis of the European building stock (BSO, 2024; Moderate, 2022-ongoing, Hotmaps, 2020) and for the assessment of its renovation potential (Birchall et al., 2014; Nemry & Uihlein, 2008; Ortega et al., 2022; Pascual et al., 2015; Pinotti & Pernetti, 2021) provided knowledge about how typologies have been defined and implemented in previous research linked to building energy retrofit. All these works rely on the approach implemented in the IEE Project TABULA (2009-2012) to define buildings typologies. The TABULA project used a “synthetic average” building approach to generate archetype buildings representing the most common features of a group of buildings in the stock based on statistical analysis. This approach generates a "virtual" building that represents a group of buildings with common features based on statistical analysis (Ballarini et al., 2014).

The potential of using building archetypes lies in the data-driven approach, which can leverage extensive datasets to better understand building energy performance trends and enable targeted energy efficiency strategies and policies. However, the data-driven approach also faces challenges related to data quality, computational resources, and model interpretability. The archetype approach may not be suitable for representing historic buildings that do not comply with standard features. In fact, the cited works do not deal with heritage significance of historic buildings. TABULA building archetypes do not capture the characteristics of a large part of historic buildings.

Research dealing with the renovation of historic buildings (Association Ajena, 2022; EFFESUS consortium, 2016; Janvier et al., 2011; Leijonhufvud et al., 2021; Pascual et al., 2015; Stiernon et al., 2017, Napier, 2018) has focused primarily on real exemplary buildings to provide guidelines to renovate buildings with similar features. These guidelines provide useful inputs for the renovation of other historic buildings. However, their application on a large scale is still limited by the lack of typology-based retrofitting scenarios.

Defining typologies for historic buildings means addressing the existing gap between virtual statistical archetypes and real exemplary buildings. To be representative, historic building typologies must be defined by considering the variable range of features of real historic buildings. Furthermore, it has been already demonstrated that, when including historic buildings within the categorization of the existing building stock, there is a need for more comprehensive categorization methods that consider also their unique characteristics (Briz, 2020). Therefore, FuturHist applies the concept of typology to historic buildings by defining geometrical and non-geometrical parameters of buildings as well as recurring heritage features. This approach allows to enhance the decision-making process for the energy retrofit of historic buildings by defining common typologies of buildings of heritage significance.

There were 23 features identified which included both quantitative and qualitative information to describe the tangible and intangible qualities of a historic building typology. These features were divided in two levels:

1. Defining features (1-13): essential parameters to classify a building within the typology
2. Variable features (14-23): additional parameters representing recurring, but non-unique, characteristics of the typology

3.1.1. Defining features

Table 4 offers an overview of the 13 defining features. These features include general information (1-4), geometric parameters (5-8), architectural characteristics (9-12) and heritage elements to be preserved (13). These features differentiate historic building typologies from one another. Therefore, they all refer to the original state of the building. As shown in the table, most features can be chosen from a predefined set of descriptions or numerical ranges to indicate what describes best each typology. Ranges, rather than exact values, are used to express quantitative values to ensure that the definitions apply to different buildings of the same typology. Instead, material properties, architectural characteristics and heritage attributes to be preserved are directly described.

General information

General information parameters define building age, location and function. The ranges of construction period (1) have been selected considering mayor changes occurred in the technological evolution of the building sector (e.g. the invention of industrialized construction elements) as well as the diffusion of architectural styles in Europe. The latter is usually linked to the socio-economic context determined by national and international events. For this reason, the ranges used for the classification are not homogenous in terms of span.

For the description of the climate context (2), this work refers to the Köppen-Geiger climate classification (Kottek et al., 2006). The original use of the building (3) describes how the typology was meant to be used when it was originally developed. The context of the original construction (4) links the typology with socio-economic changes occurring at the time of its implementation, such as rural depopulation and industrialization.

Geometric parameters

Geometrical parameters provide a description of the building in terms of shape, size and position. Footprint shape (5) allows to identify the archetypical perimeter of the typology, differentiating between different existing categories of shapes (Hu et al., 2022). Three footprint area ranges (6) allow the quantification of the extent of ground used by the building. These ranges have been selected based on the 30th and 70th percentile calculated for the European buildings stock (Moderate, 2024). The addition of floor surface area ranges (7) allows to understand the actual size of the buildings. Three floor surface ranges have been established based on previous classification of building stock by size at European level (Economidou et al., 2011). Geometrical parameters are completed by a description of the position of the building with respect to surrounding buildings (8).

Architectural characteristics

Architectural characteristics include material and typological characteristics of buildings. When applicable, the indication of the architectural style (9) associated to the typology is useful to better situate the typology within a specific socio-economic context. Not every building can be associated with an architectural style; for this reason, the corresponding feature is meant to be omitted if not applicable. However, the following parameters allows for a detailed enough description of the material and spatial qualities of the typology.

The description of the envelope construction (10) includes basic information about the material and the construction method used to build the elements that separate indoor space from outdoor space: wall, roof, floor, and windows. These parameters are defined following the approach implemented within the EU BSO (2024). The window-to-wall ratio (11) is included as a defining feature because it adds to the identification of the typology in terms of use, construction technologies and thermal behaviour. The three ranges indicated have been selected based on the 30th and 70th percentile calculated for the European buildings stock (Moderate, 2024).

Further architectural defining features can be included for each typology providing a description of the recurring typological elements in terms of internal layout, natural light, bioclimatic aspects and internal circulation schemes (12).

Heritage attributes

The retrofitting solutions will be developed in FuturHist considering the heritage value of historic buildings. For this reason, every typology has been associated with a list of attributes linked to its heritage value. The list can include building elements (e.g., a particular type of window), building construction (e.g., a specific type of wall) and decorative elements inside or outside (e.g., artistic finishings such as internal cornices or decoration scheme).

This open parameter results from the adoption of a bottom-up approach for the definition of the typology. It has been claimed as necessary for the description of the historic building stock because of its heterogeneity (Haas et al., 2021). By listing the recurring elements which embody the cultural significance of each typology, it is possible to identify which of the general, geometrical and architectural defining features (1-11) possess heritage value.

Table 4. Defining features of typologies in FuturHist.

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*Multiple choice:* • *Before 1600* • *1600-1750* • *1750-1850* • *1850-1900* • *1900-1920* • *1920-1945*
	2	Climate	*Köppen-Geiger climate class*
	3	Original use	*Multiple choice:* • *Residential* • *Service* • *Mixed*
	4	Context	*Multiple choice:* • *Urban* • *Suburban* • *Rural*
Geometric parameters	5	Footprint shape	*Multiple choice:* • *O-shape (i.e., square/circle-like)* • *I-shape (i.e., rectangular)* • *L/U/C-shape* • *F/E/H/T/Y/Z-shape*
	6	Footprint area (range)	*Multiple choice:* • *Small (<150 m^2)* • *Medium (150<>300 m^2)* • *Large (>300 m^2)*
	7	Floor surface area (range)	*Multiple choice:* • *Small (<200 m^2)* • *Medium (200<>1000 m^2)* • *Large (>1000 m^2)*
	8	Situation	*Multiple choice:* • *Detached (stand-alone building)* • *Semi-detached (adjoining building on one side)* • *Infill (adjoining buildings on two or more sides)*
Architectural characteristics	9	Architectural Style	*Name of architectural style(s) (if applicable)*
	10	Envelope construction	*Description of material and construction type for: wall, roof, floor, windows*
	11	WWR (range)	*Multiple choice:* • *Small (<20%)* • *Medium (20%<>30%)* • *Large (>30%)*
	12	Space layout/natural light/bioclimatic aspects (including heating, cooling and ventilation strategies)/ internal circulation scheme	*Description*
Heritage attributes	13	Heritage attributes to be preserved	*List of internal and/or external elements*

3.1.2. Variable features

The process of identifying the features to define the building typologies addressed in FuturHist led to the production of an additional list of features describing also the typical current characteristics of the buildings belonging to each typology. Table 5 offers an overview of the 11 variable features identified to add to the description of each typology it in terms of occupancy (14), spatial situation (15-16) and cultural value (17-23). Even if they don't define the typology, these variable features can impact on the design and the feasibility of retrofitting solutions. Therefore, the inclusion of these features representing the recurring condition of each typology is useful for setting the scope of different retrofitting intervention within each typology.

Occupancy

The indication of the typical occupancy pattern of the typology (14) provides additional information about the use of the building. Occupancy determines the level of indoor comfort required within a building and it is helpful to assess the targets (e.g. energy consumption and carbon emissions) of energy-efficient retrofitting measures.

Spatial situation

Information about the typical spatial situation of the typology completes the description of the architectural features. The indication of the typical surroundings of the building (15) allows to understand the original relationship of the building with its outdoor space. The list of buffer spaces (16), instead, deepens the understanding of the thermal behaviour of the building in relation to its position and its use.

Heritage value

The heritage value of a building can be described by its formal protection status and its attributes of significance. Both are building specific: whilst there might occasionally be some overlaps between different buildings, it is not possible to use this information to define a typology. However, when considering a typology of historic building (defined by the features presented in the previous section), it is possible to indicate a recurring characteristic related to the cultural values at national level. For this purpose, a list of regulatory and descriptive features has been drawn up to provide information about the typical characteristics of historic building belonging to the same typology. Cultural value is first described by the typical level of protection applied to buildings of the same typology (17) and them belonging to conservation (protected) areas (18).

Heritage protection levels for buildings are established on a national basis. Therefore, the classification of heritage buildings can vary significantly from one country to another, leading to significant differences in how many buildings are protected by law and which protection measures are enforced (Pinčíková, 2024). However, the analysis of the heritage protection levels of the four countries in which the typologies are located has allowed to identify similarities between different grading systems. Based on these similarities, three levels of protection have been chosen to describe the typical protection status of each typology: high (exceptional value/international recognition); medium (national interest), low (local interest, partial protection). Furthermore, historic buildings are often located within conservation areas to which special protection measures can be applied. For this reason, the position of a building within a conservation area also constitutes an element to describe its cultural value.

Intangible and qualitative features add to the description of the cultural value of a building, providing more information about its state of preservation, its rarity, its representativeness and the different aspects (or attributes) of cultural significance. Two features have been defined to describe on a scale from 1 (maximum) to 5 (minimum) the typical state of preservation of buildings belonging to a same typology: authenticity (19) and integrity (20). Authenticity refers to the preservation of the original function, meaning and use; integrity, instead, refers to the preservation of the material qualities of the building (UNESCO World Heritage, 2024). A scale from 1 to 5 is also associated the features describing the rarity of the building at local level (21) and its grade of representativeness (22) in relation to a specific function (e.g., residential, service). The cultural value of each typology is further detailed through a list of significant interests (23), which vary by case depending on scale and use, such as archaeological, aesthetic, technical, architectural, historic, urban planning, artistic, memorial, or landscape significance."

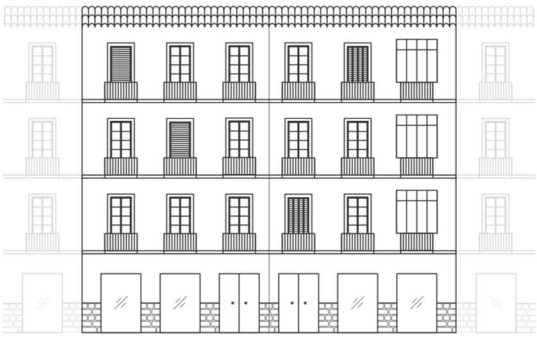
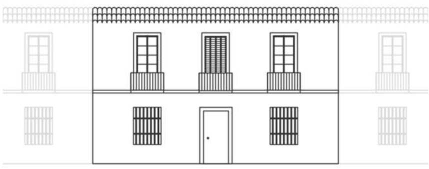
Table 5. Variable features of typologies in FuturHist.

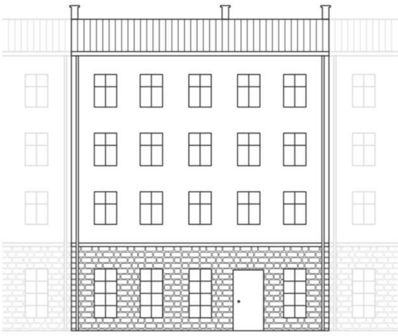
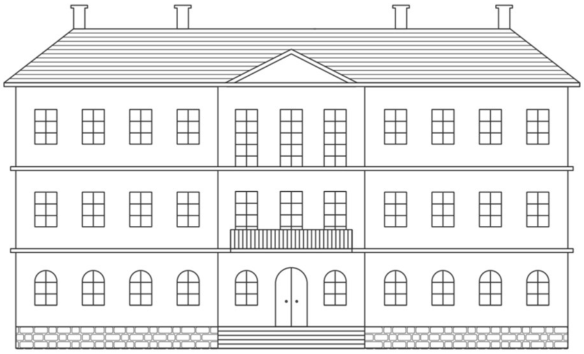
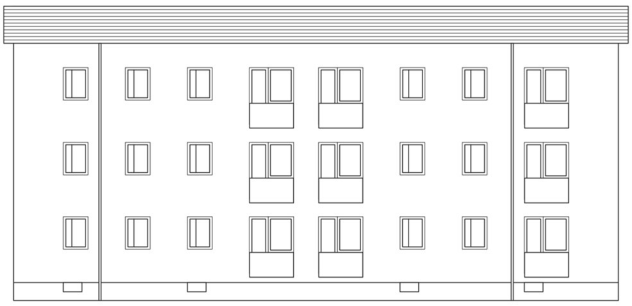
Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Multiple choice:* • *Permanent* • *Seasonal*
Spatial situation	15	Surroundings	*Multiple choice:* • *Front yard* • *Back yard* • *Courtyard* • *None*
	16	Buffer spaces	*Multiple choice:* • *Attic* • *Basement* • *Adjacent space* • *None*
Heritage value	17	Typical level of protection	*Multiple choice:* • *High (Exceptional value, international interest)* • *Medium (National interest)* • *Low (Regional or local interest, partial protection)*
	18	Conservation area	*Multiple choice:* • *Yes* • *No*
	19	Authenticity	*Preservation of the original meaning/use/function (1 to 5, 1 is the maximum)*
	20	Integrity	*Wholeness and intactness of the original materials (1 to 5, 1 is the maximum)*
	21	Rarity	*The property is locally unique, rare or exceptional, even if fragmentary, in terms of its typology, style, dating or social or historic interest (1 to 5, 1 is the maximum)*
	22	Representativeness	*The property possesses architectural characteristics linked to a specific function (1 to 5, 1 is the maximum)*
	23	Interests	*List all that applies:* • *Archaeological* • *Aesthetic* • *Technical* • *Architectural* • *Historic* • *Urban Planning* • *Artistic* • *Memorial* • *Landscape*

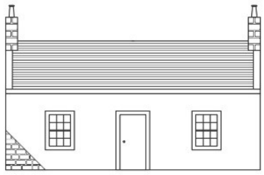
3.2 The nine defined typologies

Table 6 lists the nine typologies defined to be used in FuturHist providing a short name and a concise description; an icon is associated to each typology. The following sections contain the main outcome of this task: the description of the nine typologies that are addressed in the project and the quantification of their energy performance. The typologies are presented by country; the presentation of each typology follows a consistent structure. First, a text is provided to contextualize each typology within its national context, providing both qualitative and quantitative assessment its representativeness. Second, the typology is described by filling in the tables of features explained in the previous section. Third, the energy performance of the typology is presented.

Table 6. Icons and names of the nine typologies defined in this task to be used in FuturHist.

Icon	***Typology***
	***Casa de pisos*** *Spanish terraced tenement building* *(1600-1920)*
	***Patio de vecinos*** *Spanish terraced courtyard tenement building* *(1600-1920)*

	***Kamienica*** *Polish terraced tenement building* *(1750-1945)*
	***Willa miejska*** *Polish garden-city/urban villa* *(1900-1945)*
	***Monumentalbyggnad*** *Swedish monumental public building* *(1850-1920)*
	***Flerbostadshus funktionalism*** *Swedish functionalist multi-family housing block* *(1920-1945)*

	***Georgian cottage*** *Scottish Georgian detached cottage* *(1750-1850)*
	***Georgian tenement*** *Scottish Georgian terraced tenement building* *(1750-1850)*
	***Victorian terraced house*** *Scottish Victorian terraced house* *(1850-1920)*

3.3. Casa de pisos: Spanish terraced tenement building (1600-1920):

3.3.1 Contextualization of the typology

Origin and diffusion

“Casa de pisos” (multi-storey multifamily building with a common staircase) is the typology defined for the demonstrator building located in Spain (Figure 3). In Andalusian historic centres, “casa de pisos” is one of the most common typologies of residential buildings. This typology is primarily associated with the historic city centres and plays an important role in the historic urban fabric especially in cities such as Malaga, Seville and Cadiz. Although there are cases from earlier centuries in Cadiz, most of them often date from the 19th and early 20th centuries when cities experienced vertical growth to make the most of urban land. During the 17th and 18th centuries there was a period of economic growth in Andalusia derived from trade with America and many Andalusian cities, such as Cadiz or Seville grew in population, and in the case of Cadiz, in a limited urban space within the historic centres. This fact together with the emergence of a new society with new needs, led to the massive use of multi-family buildings and an increase in building height. Therefore, this typology arose as a response to the lack of space available for building in historic centres, but also in response to the organisational needs of a new society. These buildings were designed to accommodate commercial activities on the ground floor and dwellings in the upper levels (Figure 4).

Figure 3. Spanish demonstrator building. Antonio Ramos Valdés, Plaza Corredera 16-17. Córdoba. Photo: AVRA

According to EU BSO (2024), multifamily houses and apartment blocks realized before 1945 correspond to **3,2%** of the buildings in Spain. Furthermore, the dwellings corresponding to multifamily houses and apartment blocks realized before 1945 constitute **5%** of the dwellings recorded at national level. Multifamily residential buildings realized in Spain before 1945 were built in urban context, where the main building type were the “casa de pisos” and the “patio de vecinos”. Data extracted from the *Instituto Nacional de Estadística* show the diffusion of these residential typologies at local level. In Andalucia, Multifamily dwellings built before 1950 represent a **2.22%** of the whole dwelling stock. Considering main Andalusian cities, multifamily dwellings built before 1950 represents a **4.38%** of the whole dwelling stock (census 2021). In Córdoba, **1.41%** of the dwellings were realized before 1950. Furthermore, multifamily dwellings realized before 1950 and located in the historic centre of Cordoba represent 0.55% of the city’s building stock.

Figure 4. Terraced tenement building in Calle Sacramento 36, Cádiz., 19th century. Photo: AVRA

The *Plan General de Ordenación Urbana de Sevilla* (General Urban Plan of Sevilla,2006) describes the “Casa de Pisos” as those “buildings of multi-family dwellings from the late 19th and early 20th centuries, characterised by their façade, the layout of their significant elements (entrance hall, staircase, courtyards, etc.), or by their interior alignments.”. This typology, aligned to the street, generally has a height of 3-4 floors and a staircase in the second or third bay and is a further step in the adaptation and evolution of the single-family casa patio into a collective housing, a “patio de vecinos” (see 3.4. Patio de vecinos: Spanish terraced courtyard tenement building (1600-1920)).

In this case, a morphological transformation reduced or even removed entirely free spaces such as courtyards or galleries, and the buildings adapt to the urban fabric of the streets or squares that become the space for collective relations. This typological and morphological transformation occurred also in other cities in search for alignments, ornamentation and health guidelines inherited from the Age of Enlightenment principles as seen in the main European cities. Depending on the era, façade styles and staircase placement within the building may vary. In some cases, these changes are influenced by hygienist principles.

Many of these buildings are protected by heritage regulations due to their architectural and cultural value and even more, listed as *Bien de Interés Cultural* (Assets of Cultural Interest), which restricts architectural and energy interventions. Energy refurbishment of this typology poses complex challenges due to the vertical structure, protected facades and the need to balance energy efficiency with heritage conservation.

Architectural features and retrofitting challenges

Typically, historic buildings of Andalucian city centres were built with thick load-bearing wall systems, high ceilings, decorated façades with balconies and cast-iron railings, and Arabic ceramic tiles or “azoteas” (flat rooftops). The overall formal expression of the building there is a predominance of the massif over the hollow. These features must be generally preserved during the interventions.

Despite the advantages of thick walls for passive thermal regulation, these buildings can present thermal comfort issues due to inadequate insulation, significant air leakage from windows, and the difficulty of conditioning spaces with high ceilings. Additionally, the vertical configuration can make upper floors more exposed to heat in summer and cold in winter, while lower floors, which are cooler, may suffer from a lack of natural light and dampness.

3.3.2. Defining features of the typology

Table 7. Defining features of Spanish typology "casa de pisos".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1600-1920*
	2	Climate	*Csa Köppen-Geiger climate class*
	3	Original use	*Mixed*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	*Medium (150<>300 m²)*
	7	Floor surface area (range)	*Medium (200<>1000 m²)*
	8	Situation	*Infill (adjoining buildings on two or more sides)*
Architectural characteristics	9	Architectural Style	*Baroque/Neoclassical/Modern Style*
	10	Envelope construction	• *Solid brick/stone walls (~50-70 cm-thick)* • *Pitched roof, wooden beams, clay tiles* • *Mortar floor covered with ceramic tiles* • *Casement windows, single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Plan organized within parallel vertical loadbearing structures* •
Heritage attributes	13	Heritage attributes to be preserved	• *Roof: sloping and ceramic tiled roof* • *Façade: traditional load-bearing wall with constant proportion of vertical openings* • *Coating: lime mortar* • *Finishing: paint colour* • *Windows: vertical wooden swing door with inward opening* • *Finishing: surface treatments*

3.3.3. Variable features of the typology

Table 8. Variable features of Spanish typology "casa de pisos".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	*Front yard*
	16	Buffer spaces	*Adjacent space*
Heritage values	17	Typical level of protection	*Medium (National interest)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*2*
	20	Integrity (1:max-5:min)	*2*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Architectural* • *Historic* • *Urban Planning*

3.3.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 5 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the external walls of this typology are built of 50 to 70 cm-thick solid brick or 60 cm thick stone structures. U-values from RIBuild (2020) have been interpolated to obtain a value that match the wall thickness of this typology. Calculated data for the construction type of the demo case (40 cm thick solid brick wall) corresponds to a lower U-value compared to the data of typical Spanish construction realized before 1945. Due to the large variety of walls within this typology, all data collected is considered applicable; the U-value range proposed for the walls of this typology is **0,76-2,75 W/(m²*K).**

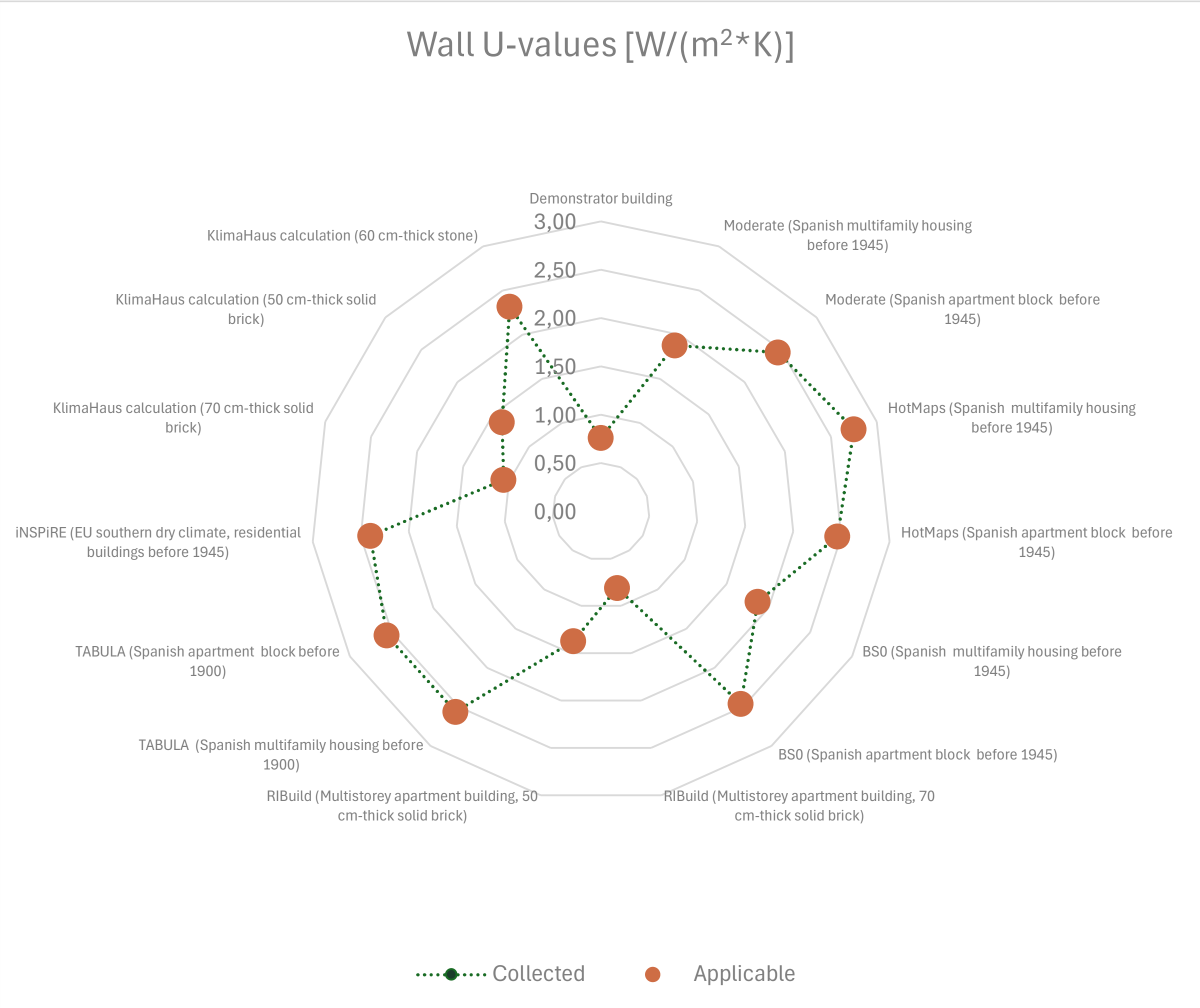


Figure 5. U-values identified for walls of multifamily buildings with similar features to the typology "casa de pisos".

Roof

Figure 6 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure covered with clay roof tiles. The U-value for the demonstrator's roof has not been considered for the range, as it corresponds to a renovated element with additional thermal insulation. The U-value range generated for the roof of this typology is **1,73-5,00 W/(m²*K).** This range is quite wide because of the variability of the structural layers within the typology.

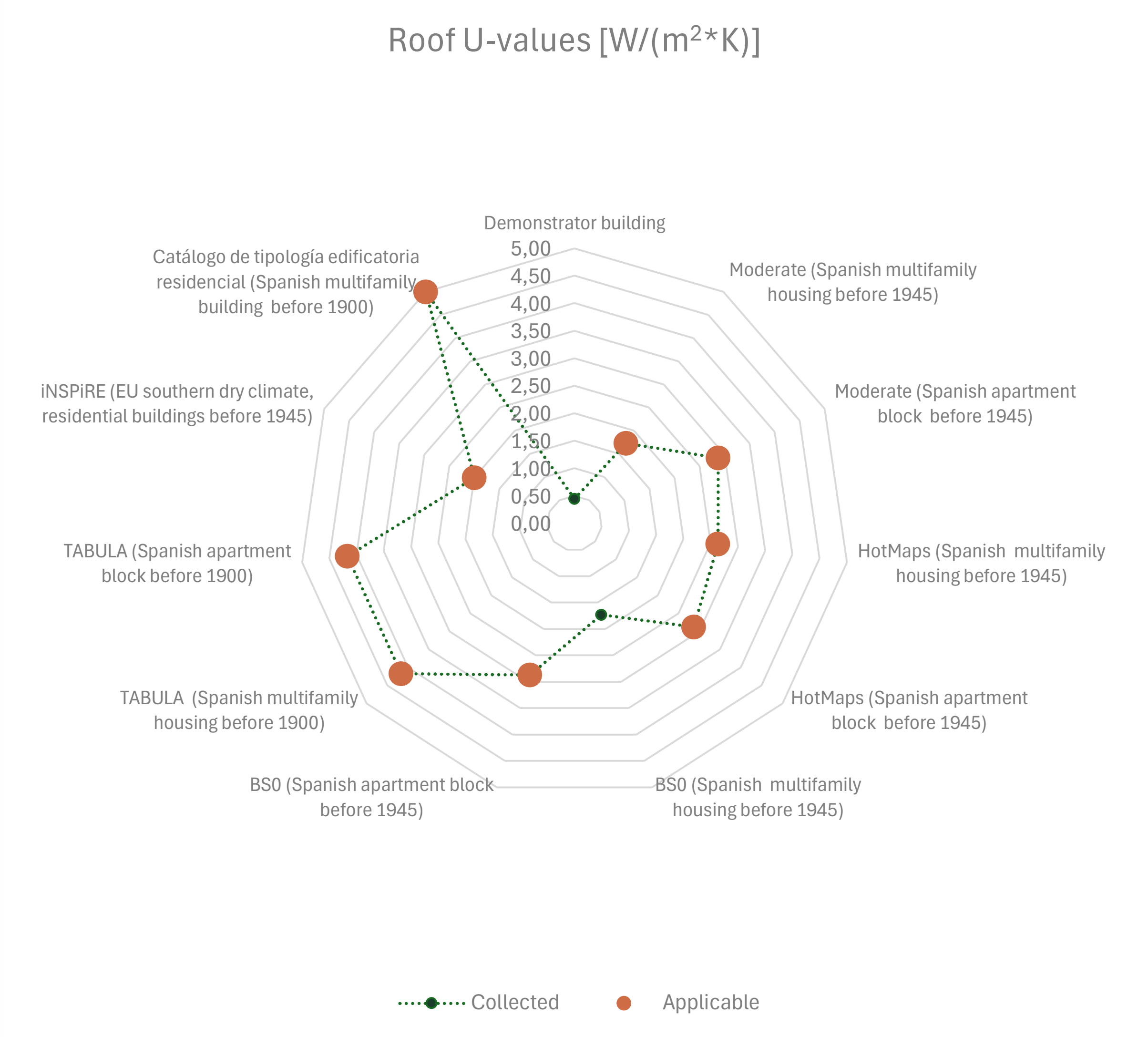


Figure 6. U-values identified for roofs of multifamily buildings with similar features to the typology "casa de pisos".

Floor

Figure 7 provides an overview of the data collected to define a U-value range for the floor of this typology. The original construction for the floor of the lower level of this typology is built of mortar and ceramic tiles. Some of the collected U-values, including the one of the demonstrator building (where a concrete structure has been integrated in the floor slab), correspond to different floor constructions; therefore, they have not been considered to generate the range. To increase accuracy of the range, the U-value corresponding to this structure has been performed with ProKlimaHaus. The following U-value range has been defined for this element: **1,07-2,60 W/(m²*K).**

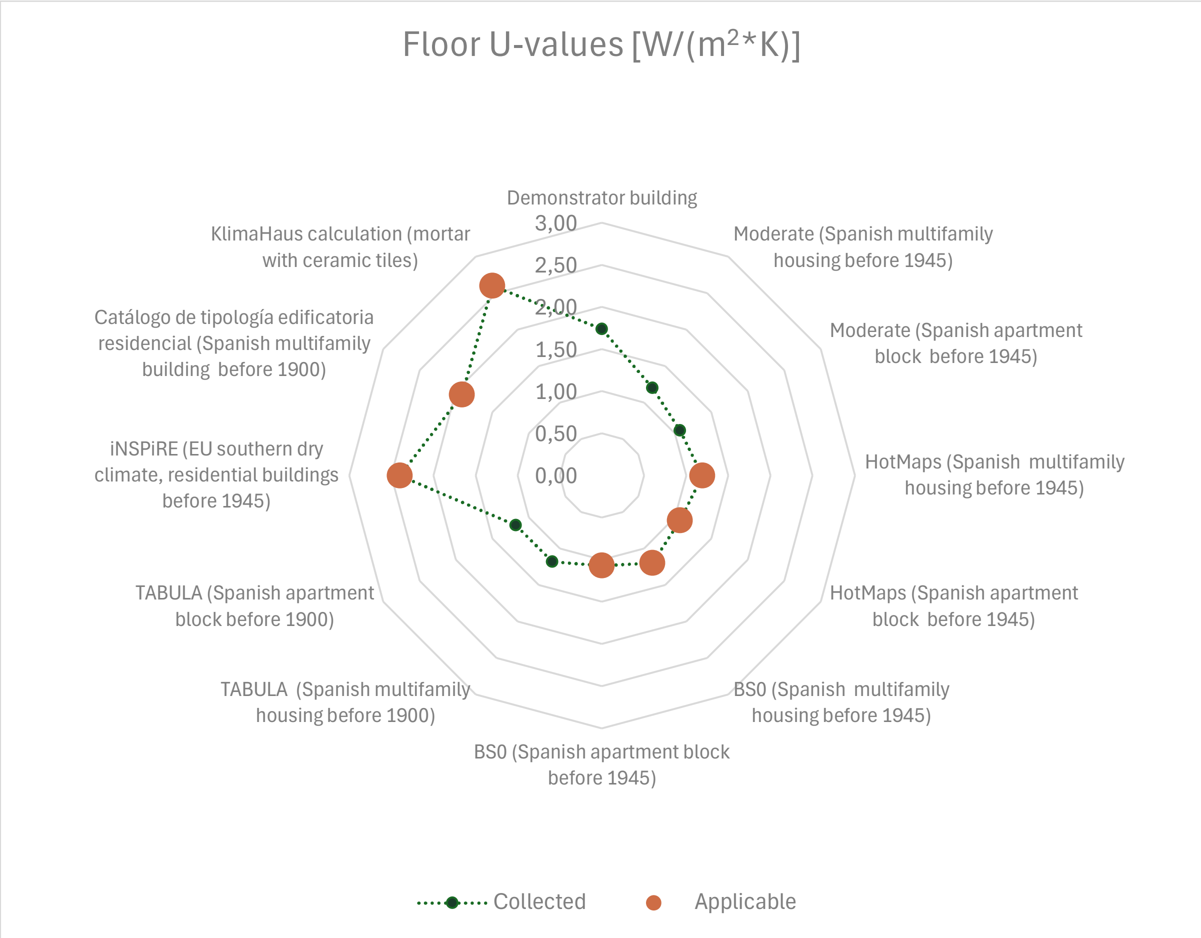


Figure 7. U-values identified for floors of multifamily buildings with similar features to the typology "casa de pisos".

Windows

Figure 7 provides an overview of the data collected to define a U-value range for the windows of this typology. These are built of wooden frames and single glazing. The U-value range generated for the windows of this typology is **3,92- 5,47 W/(m²*K).** The windows of the demonstrator building have a large proportion of timber resulting in a lower U-value. The inclusion of this value, considered to be representative, allowed to lower the minimum level of the range.

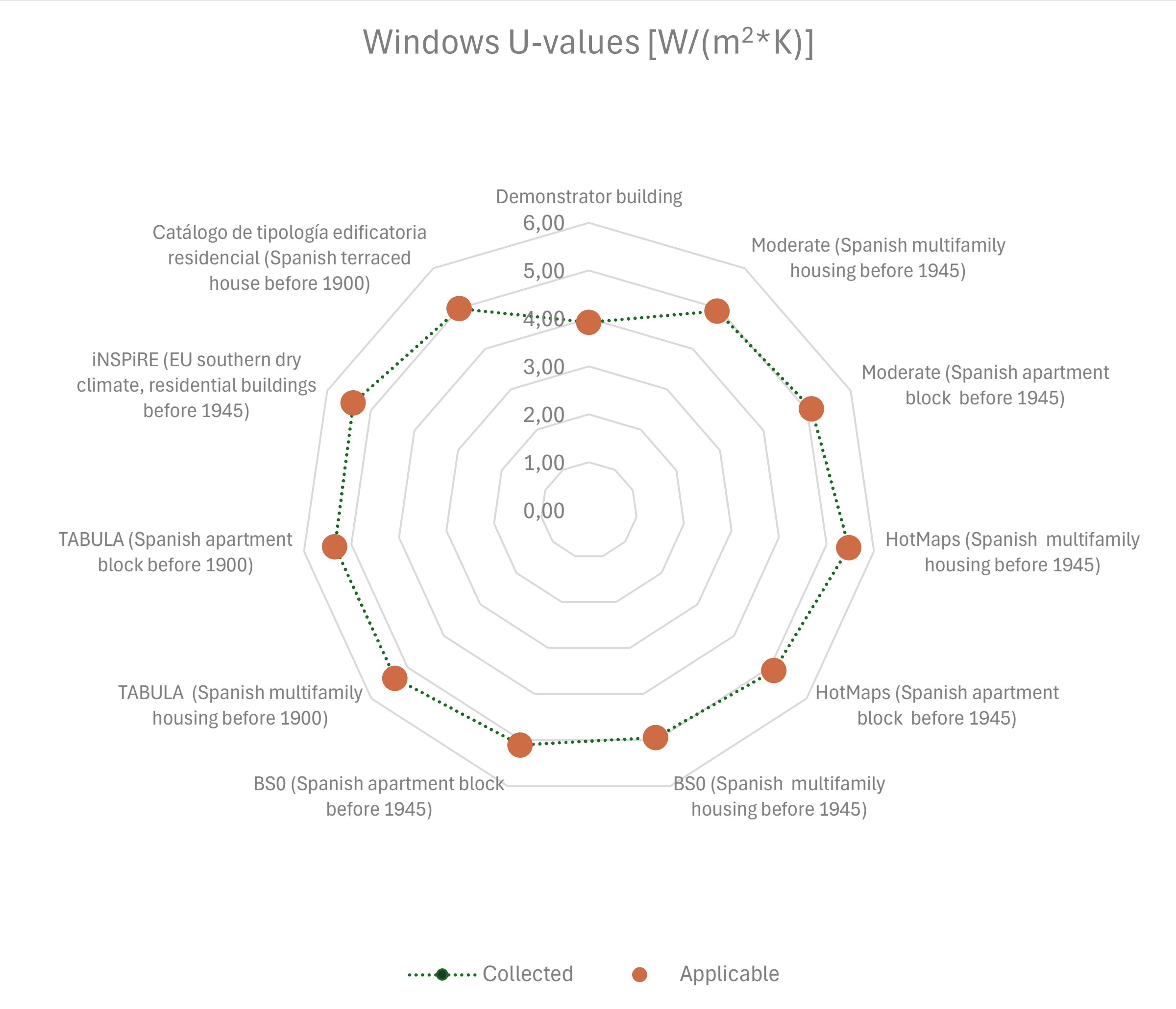


Figure 8. U-values identified for windows of multifamily buildings with similar features to the typology "casa de pisos".

Energy demand and consumption for heating and cooling

Figure 9 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. Data collected from TABULA referring to Spanish residential buildings located in mediterranean climate have been excluded from the range as they refer to buildings with a heating demand too low to be considered for energy retrofit. The ranges identified for energy demand are the following:

- Heating: **59-123 kWh/m² year**
- Cooling: **50-70 kWh/m² year**
- Heating and cooling: **110-193 kWh/m² year**

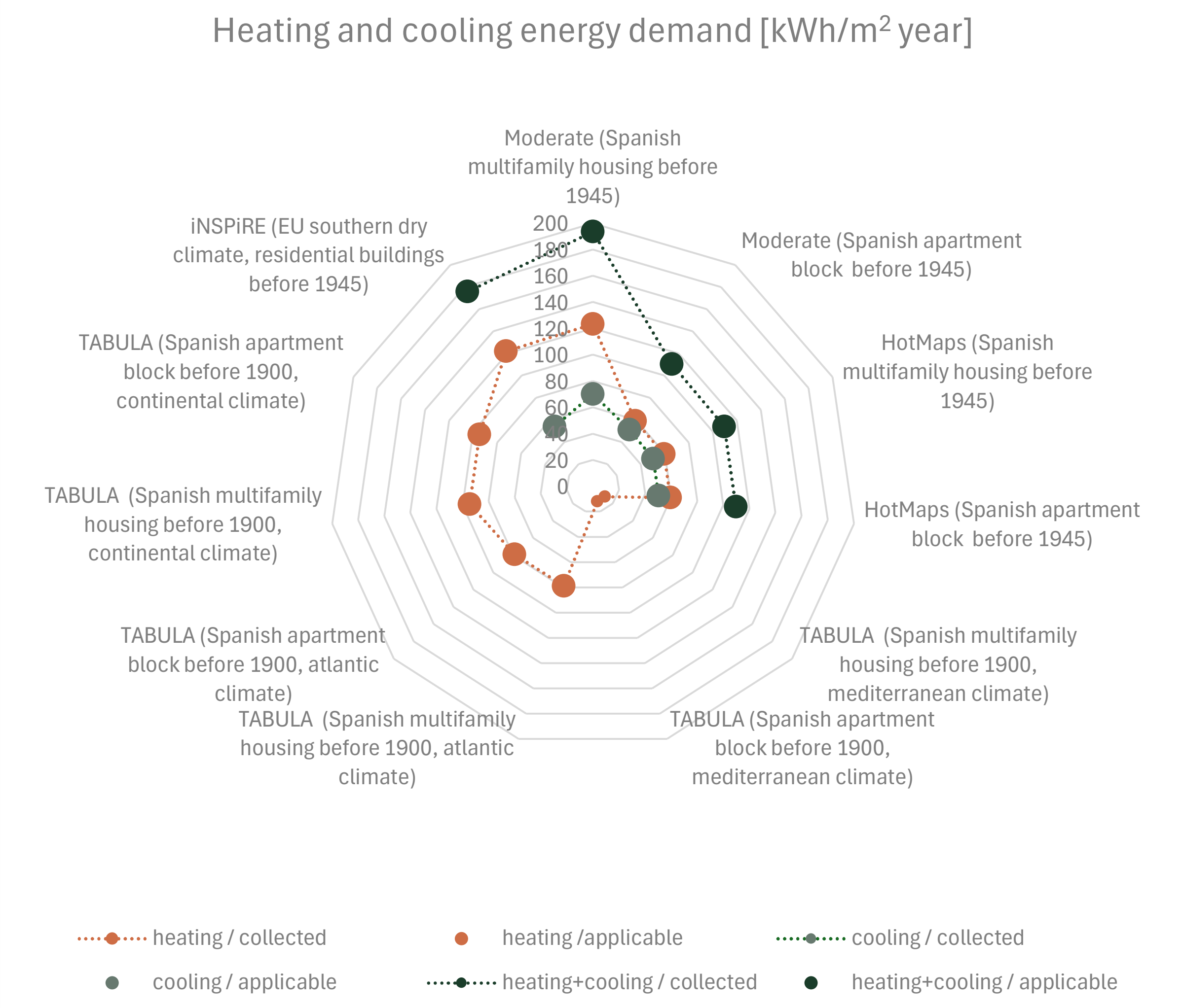


Figure 9. Energy demand data for heating and cooling identified for multifamily buildings with similar features to the typology "casa de pisos".

Some of the data sources used to collect information about heating demand also provided quantification of the energy consumption for heating and cooling (Figure 10). The ranges identified for energy consumption are the following:

- Heating: **101-210 kWh/m² year**
- Cooling: **15-20 kWh/m² year**
- Heating and cooling: **115-230 kWh/m² year**

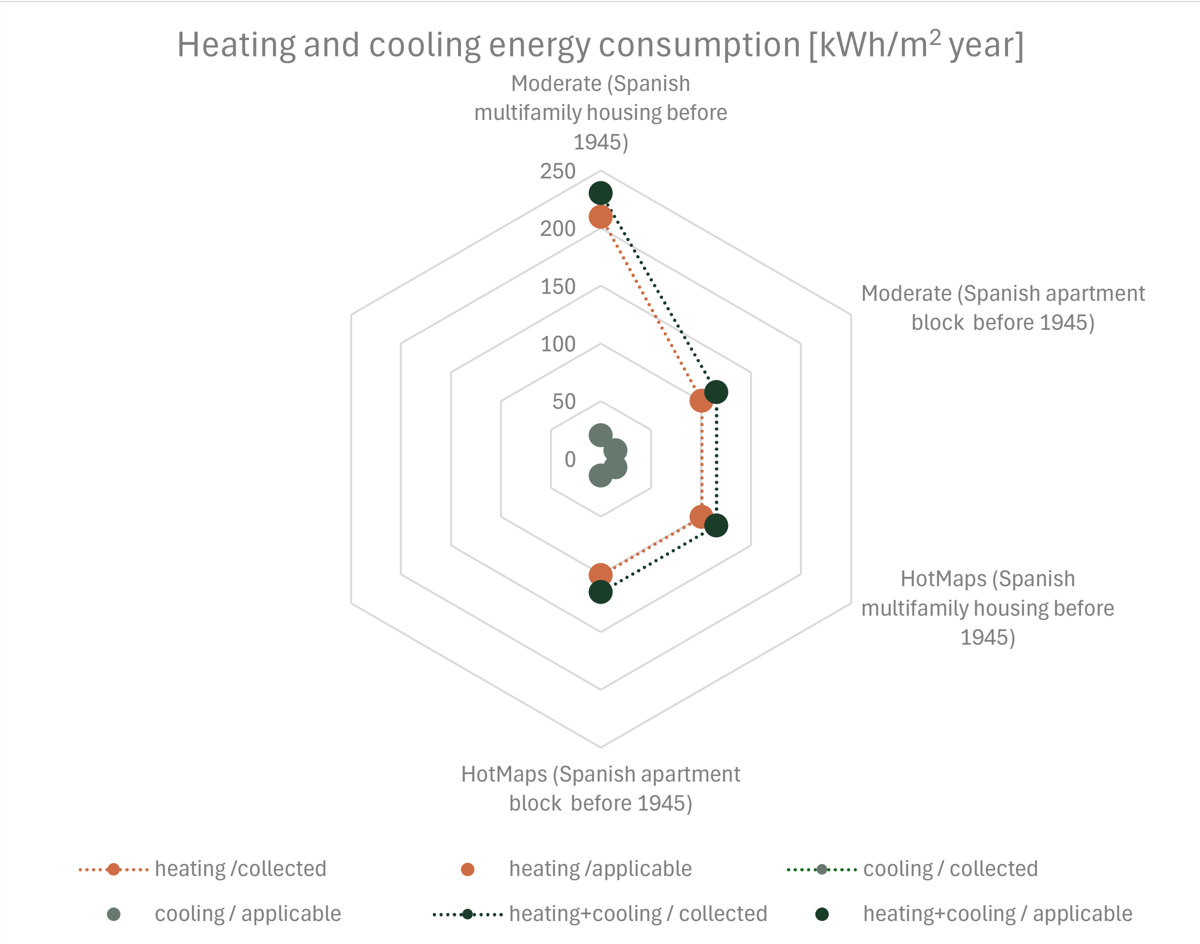


Figure 10. Energy consumption data for heating and cooling identified for multifamily buildings with similar features to the typology "casa de pisos".

3.4. Patio de vecinos: Spanish terraced courtyard tenement building (1600-1920)

3.4.1. Contextualization of the typology

Origin and diffusion

The "patio de vecinos" (courtyard multifamily house) typology is a traditional architectural style found in Andalusia, particularly in cities such as Cádiz, Córdoba, Seville, and Granada. This typology is defined in FuturHist to include also “corrales de vecinos”, a similar residential typology whose origin arose because of the use of a courtyard house (Casa Patio) by several neighbours, generally during the 19th century (Figure 11). The patio house is a traditional Mediterranean housing type with a high heritage value, both tangible and intangible in which the “patio” plays the central role (spatial, functional and symbolic), structuring the dwellings and access and the social life of its inhabitants and solving the needs of lighting, ventilation and regulating climatic conditions. Their presence in historic centres can be used to recover the environmental values of the Mediterranean city.

Figure 11. Casa de vecinos in XVIIth century "Casa Palacio" in calle Ramón de Cala, Jerez de la Frontera (Cádiz). Photo AVRA.

Patio houses in Andalusia, as in many Mediterranean cities, date back to its origin in which the “patio” has coexisted and evolved with the different civilisations and has been adapted to the different social changes. In the Iberian Peninsula, the Roman and later Muslim tradition of the courtyard, which was embodied in Andalusian architecture, has survived and left as a legacy the well-known Andalusian courtyard, where is a clear leading typology in Andalusian city centres. Many of these buildings, characterized by shared central courtyards (patios), are listed due to their cultural, historic, and architectural value, as they were transformed from former palace-houses, courtyard-houses (casas patios) or former convents to provide accommodation for several families generally belonging to the urban working class.

However, there are other cases of corralas and patios de vecinos built ex-profeso to provide accommodation for people coming from the massive rural-urban exodus that took place in the 19th century. They usually occupied blocks or empty spaces in the urban fabric. The dwellings in these buildings were distributed around galleries leading to a central or side courtyard. In this courtyard there was usually a water well or fountain and other communal areas, which in some cases could be built around a secondary courtyard.

As previously anticipated, the percentage of multifamily houses and apartment blocks realized before 1945 in Spain presented in the contextualization of the previous typology (casa de pisos) also apply to the typology of the patio de vecinos. These two typologies correspond to most of the multifamily residential building stock realized in Spain before 1945 (i.e., **3,2%** of the buildings and **5%** of the dwellings)

Heritage significance

Depending on the size and characteristics of those buildings two categories have been established (Fernández Salinas, 2003):

1. <u>Corrales de vecinos:</u> buildings developed or transformed to accommodate a low-income population. The corrales de vecinos were a common feature in most Andalusian cities and in some other areas of Spain, although it was probably in Seville where it reached its greatest development. In cities such as Cádiz, the “corral de vecinos” has a rural origin in which people coming from the agriculture moved into the cities in search for new jobs.

2. <u>Patios de vecinos:</u> buildings, generally smaller than “corrales” developed or transformed to accommodate middle class residents with a renting tenure regime

The *Plan General de Ordenación Urbana de Sevilla Sevilla* (General Urban Plan of Sevilla, 2006) describes these typologies as:

1. "Casa patio: Generally, a single-family building, characterised by the existence of a courtyard, which is the nucleus on which the rest of the building is built. This is the nucleus on which the rest of the building is developed, together with the staircase leading to the upper floors, its location being highly conditioned by the size of the plots. This type has undergone variation in relation to the historic period of its implantation, in this way we can distinguish between the Popular Courtyard House of the 18th century or earlier, the Courtyard House of the 19th century and that of the beginning of the 20th century."

2. "Corral de vecinos: Multi-family buildings that are characterised by having a large free space inside the plot, the rest being occupied by buildings generally with one or two bays attached to the party wall, which are accessed through a gallery open to the courtyard. Within this type there are variations which, in general, coincide with the historic periods in which they were built, such as the following: Corrales Adarves before the 18th century with clear Islamic influences; Historic Corrales from the 18th and early 19th centuries; Corrales from the late 19th and early 20th centuries, whose typological relationships become more complex; and Mixed Corrales, which do not have all the elements that define the typology."

The *Plan General de Ordenación Urbana de Córdoba* (General Urban Plan of Córdoba, 2006) says for Casa de vecinos:

> "multi-family building, structured in several bays around one or more courtyards, with the possibility of secondary courtyards in the dwellings (one structuring courtyard/several structuring courtyards)

and for Corral:

> "multi-family building, structured in a bay attached to a party wall, with distribution by gallery and common facilities".

In addition to their particular heritage value, their physical characteristics make them particularly useful buildings for urban sustainability. On the other hand, the traditional ways of life in those buildings, mainly in the neighbouring houses, have encouraged their care and community life. In historic centres of cities such as Sevilla, Córdoba, Granada or Cádiz, the traditional neighbourhood has been closely linked to the figure of the corral de vecinos and the patio de vecinos. However, nowadays, these tenement houses around a courtyard are in a situation of regression and loss of their inhabitants, due to the consequences of speculation and gentrification processes to which buildings in historic city centres are being subjected.

Architectural features and retrofitting challenges

The courtyard design (Figure 12), typically surrounded by multi-story residential units, offers passive climatic benefits, such as natural ventilation and shading, as the courtyard favours bioclimatic balance, particularly when it is provided with vegetation, allowing adequate lighting and ventilation, or the use of water through its water wells and fountains. Yet these buildings often lack modern insulation and efficient heating or cooling systems.


Figure 12. Corrala in calle Barrameda en Sanlúcar de Barrameda (Cádiz) Photo: AVRA

Those buildings are characterized by the following key features:

- **Central Courtyard**: The central courtyard is the heart of the building, used as a social space and a source of light and ventilation for surrounding dwellings. One-two rooms dwellings are structured around a courtyard (or some courtyards), to which they overlook through corridors that generally give them access; those corridors or galleries can have two, three or four sides, depending on the courtyard size.

- **Collective facilities:** They had in the past, a series of collective services (outhouses, kitchens, courtyard, laundry rooms, drying rooms...). In the last decades of the 20th century, many neighbours of corrales and casas de vecinos have taken advantage of the dwellings that have been left empty to extend their dwellings to include toilets and independent kitchens.

- **Thick Walls**: These buildings are often constructed with thick masonry walls, which provide thermal inertia, regulating internal temperatures.

- **Multiple Stories**: Many Patio de Vecinos structures have multiple levels of apartments or rooms, generally 2-3 floors, whose access is via communal staircases or galleries facing the courtyard.
- **Windows**: The buildings tend to have windows opening towards the inner courtyard, maximizing natural light and cross-ventilation while reducing excessive solar heat gain in the absence of insulation.
- **Shading Features**: The design often incorporates shading elements such as balconies, overhangs, or trees in the courtyard, reducing the building's exposure to direct sunlight.
- **Social and morphological differences**: on the same plot, there was usually a clear social and morphological differentiation between the dwellings that have direct access from the street, and whose openings look directly onto the street (the *tapón* house), and the interior dwellings, structured in relation to the courtyard, to which they have a separate access from the previous one, and which look onto the interior of the plot.
- **Tenure:** the tenure regime is generally renting. However, there are cases in which the dwellings have been acquired by their traditional neighbours as long as they maintain their multi-family character, i.e. they have not been converted into a single-family building.

The position of the patio can be central or in one of the adjoining walls. In those typologies we can also find a back secondary courtyard. In both cases, the access is generally through the axis of the patio. In addition, there is also an interstitial space ("zaguan") which establishes the link between the public and the private space and the outside and inside of the building.

When it comes to retrofitting patio de vecinos buildings for energy efficiency, several challenges arise:

- **Heritage Protection**: As listed buildings, there are strict regulations governing what can be altered. Facades, windows, and structural elements must often be preserved in their original state, limiting options for external insulation or replacement of windows.
- **Ventilation and Moisture Control**: While the open courtyard aids natural

ventilation, it can also lead to uneven distribution of air and temperature. Maintaining ventilation while improving energy efficiency requires careful planning to avoid creating condensation or moisture problems inside.

- **Integration of Renewable Energy**: The communal nature of these buildings, with shared spaces and often flat or limited rooftop areas, complicates the installation of solar panels or other renewable energy sources, which may be restricted by regulations on visible changes to the exterior.

3.4.2. Defining features of the typology

Table 9. Defining features of Spanish typology "patio de vecinos".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1600-1920*
	2	Climate	*Csa Köppen-Geiger climate class*
	3	Original use	*Mixed*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	• *O-shape (i.e., square/circle-like)*
	6	Footprint area (range)	• *Medium (150<>300 m2)* • *Large (>300 m^2)*
	7	Floor surface area (range)	• *Medium (200<>1000 m^2)* *Large (>1000 m2)*
	8	Situation	• *Semi-detached (adjoining building on one side)* • *Infill (adjoining buildings on two or more sides)*
Architectural characteristics	9	Architectural Style	*NA*
	10	Envelope construction	• *Solid brick walls (~25-50 cm-thick), plastered* • *Sloping roof, wooden beams, clay tiles* • *Mortar floor covered with ceramic tiles* • *Wooden frame windows, single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Central courtyard* • *Direct lighting in all rooms* • *Solar shading* • *Cross ventilation* • *Vegetation* • *Common staircases and galleries*
Heritage attributes	13	Heritage attributes to be preserved	• *Windows dimension, position and alignment* • *External plaster* • *Façade colours* • *Wooden windows* • *Rooftop* • *Courtyard position and dimensions*

3.4.3. Variable features of the typology

Table 10. Variable features of Spanish typology "patio de vecinos".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	*Courtyard*
	16	Buffer spaces	*Basement*
Heritage values	17	Typical level of protection	*Low (Local interest, partial protection)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*3*
	20	Integrity (1:max-5:min)	*3*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Architectural* • *Ethnologic* • *Archaeological* • *Urban planning*

3.4.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 13 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the external walls of this typology are built of solid bricks, 25 to 50 cm thick. U-values from RIBuild (2020) have been interpolated to obtain values that match the thickness of the walls of the typology. Based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,37-2,23 W/(m²*K).**

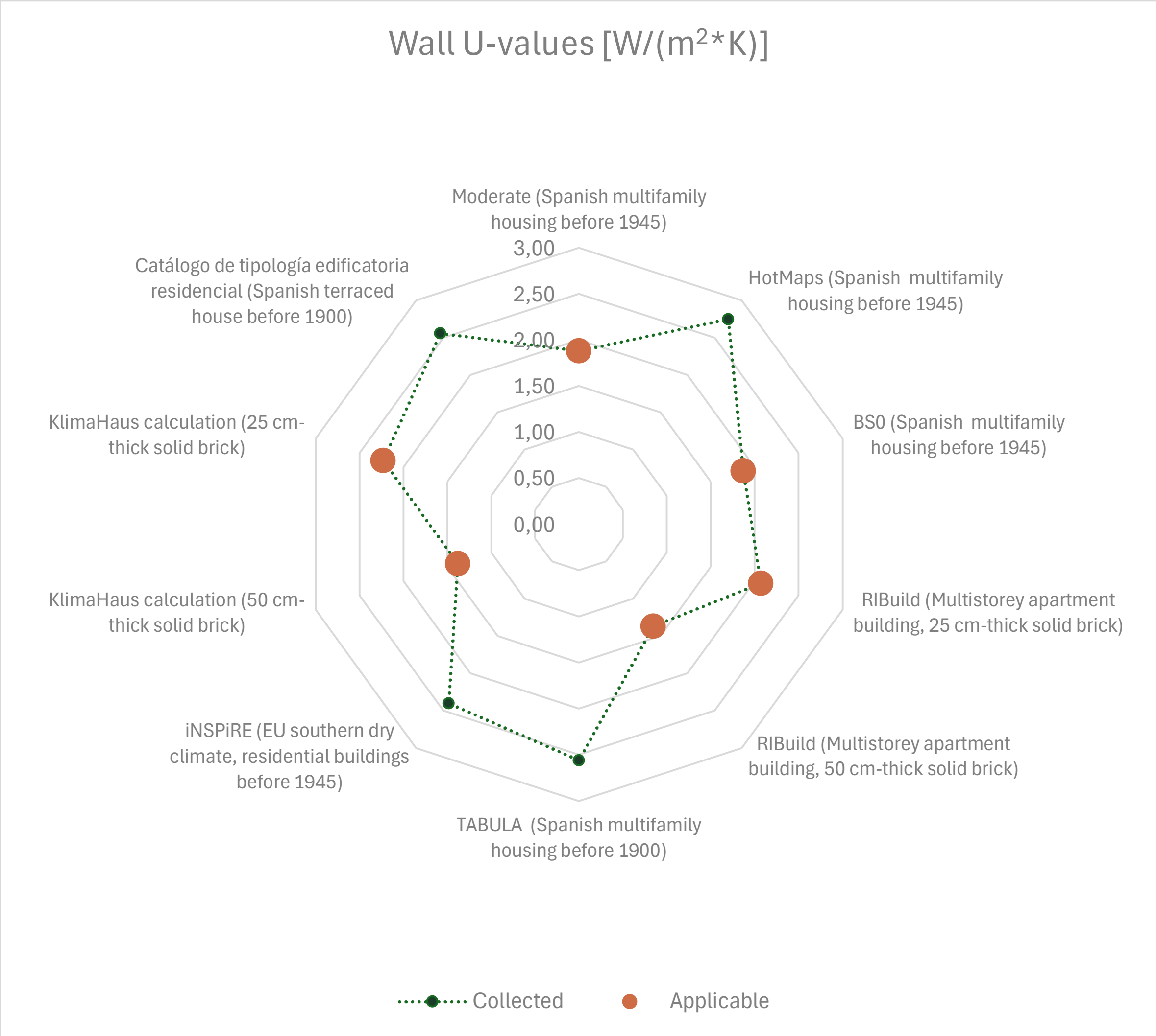


Figure 13. U-values identified for walls of multifamily buildings with similar features to the typology "patio de vecinos".

Roof

Figure 14 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure covered with ceramic roof tiles. The U-value range generated for the roof of this typology is **1,73-5,00 W/(m²*K).** This range is quite wide because of the variability of the structural layers within the typology.

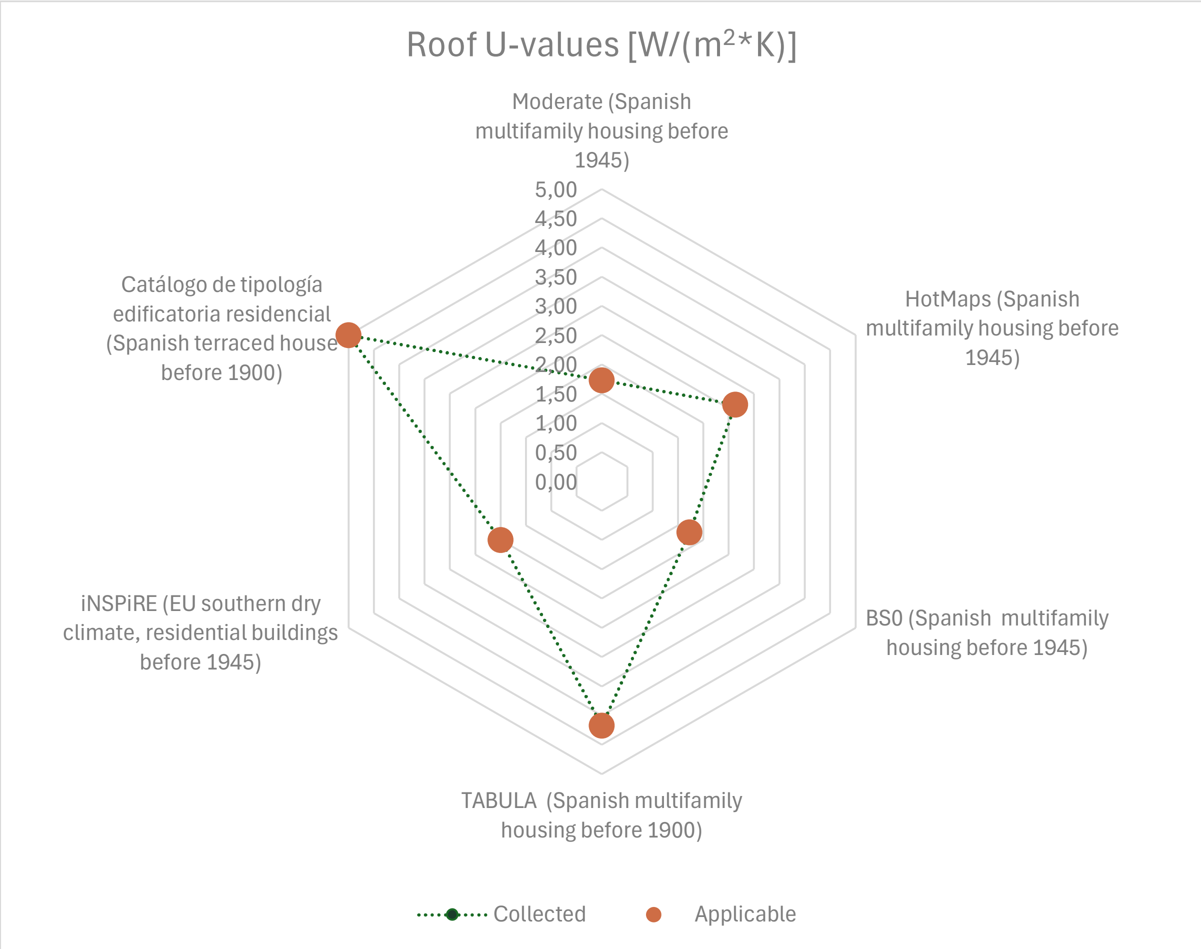


Figure 14. U-values identified for roofs of multifamily buildings with similar features to the typology "patio de vecinos".

Floor

Figure 15 provides an overview of the data collected to define a U-value range for the floor of this typology. The original floor construction associated with this typology is built of mortar and ceramic tiles. Some of the collected U-value correspond to different floor constructions; therefore, they have not been considered to generate the range. To increase accuracy of the range, the U-value corresponding to this structure has been performed with ProKlimaHaus. The following U-value range has been defined for this element: **1,19-2,60 W/(m²*K).**

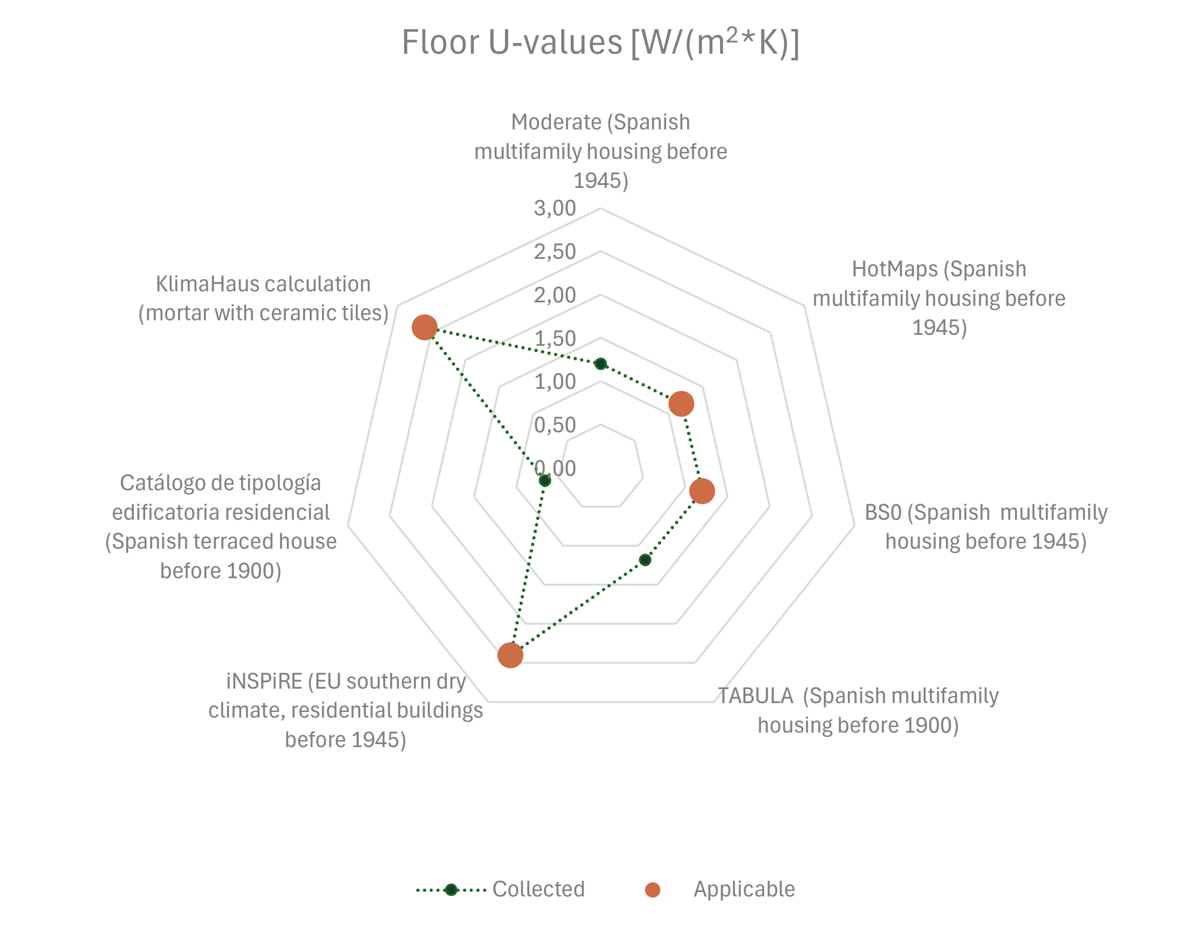


Figure 15. U-values identified for floors of multifamily buildings with similar features to the typology "patio de vecinos".

Windows

Figure 16 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. The U-value range generated for the windows of this typology is **3,92- 5,47 W/(m²*K).**

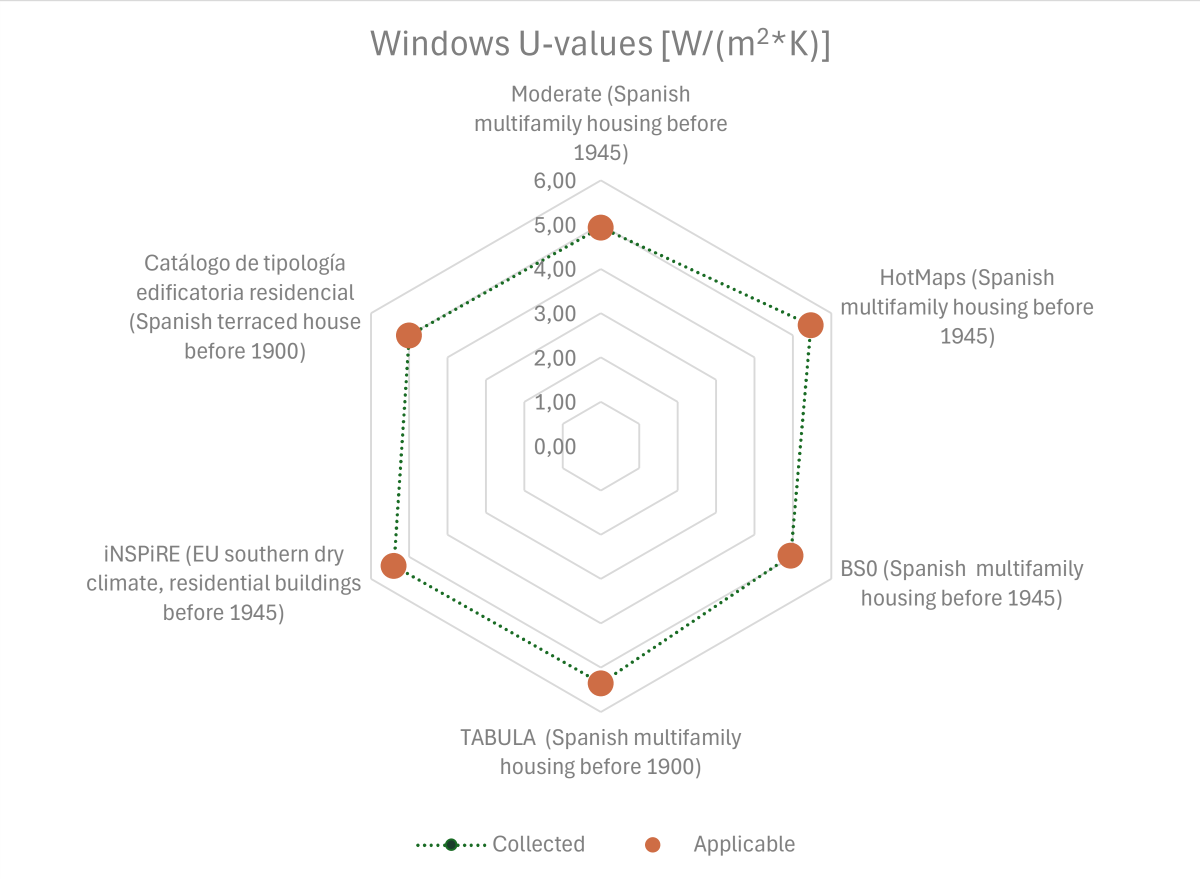


Figure 16. U-values identified for windows of multifamily buildings with similar features to the typology "patio de vecinos".

Energy demand and consumption for heating and cooling

Figure 17 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. Data collected from TABULA referring to Spanish residential buildings located in mediterranean climate have been excluded from the range as they refer to buildings with a heating demand too low to be considered for energy retrofitting. The ranges identified for energy demand are the following:

- Heating: **59-123 kWh/m² year**
- Cooling: **50-70 kWh/m² year**
- Heating and cooling: **110-193 kWh/m² year**

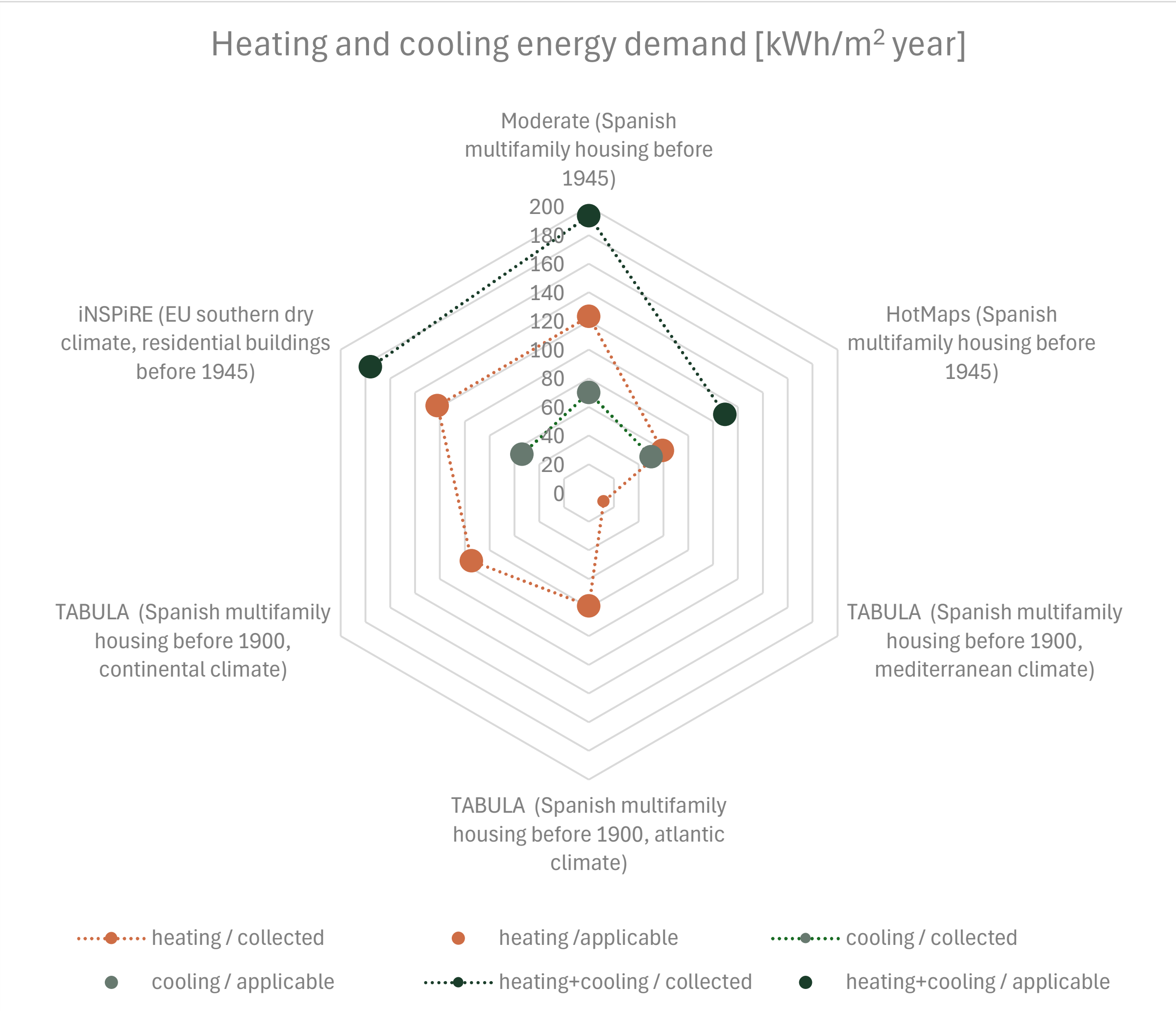


Figure 17. Energy demand data for heating and cooling identified for multifamily buildings with similar features to the typology "patio de vecinos".

Hotmaps (2020) and Moderate (2022) datasets also provided quantification of the energy average consumption for heating and cooling for Spanish multifamily housing buildings realized before 1945. The ranges identified for energy consumption from these sources are the following:

- Heating: **101-210 kWh/m^2 year**
- Cooling: **15-20 kWh/m^2 year**
- Heating and cooling: **115-230 kWh/m^2 year**

3.5. Kamienica: Polish terraced tenement building (1750-1945)

3.5.1. Contextualization of the typology

Origin and diffusion

"Kamienica" (terraced tenement) is the typology defined for the demonstrator building located in Poland (Figure 18). The demonstrator building located in Krakow presents a representative form of residential architecture of the row tenement house of the late 18th, 19th and the beginning of the 20th century (before 1918) with classical detailed, profiled cornices, rusticated and plastered on the ground floor and with bare brick, block-course above or plastered. The demonstrator building in Krakow is one of the last well-preserved buildings in its original shape and function. This type of buildings (often residential infills) is defined as a cultural, social and architectural phenomenon with historic value. They present stylistic diversity, combining local traditions with influences from capital cities of Central Europe (like Vienna, Berlin, Paris). They are often protected by law, many of them listed in the Polish Register of Historic Monuments.

Figure 18. Terraced house in 18 Kościuszki St., Krakow. Polish demonstrator building. Photo: E. Szpakowska-Loranc 2024.

The buildings of kamienica type are located in the historic city centres of Poland. Built as infills or corners in continuous perimeter blocks (Figure 19), they are typically 2-4 stories high, one or multi-staircase, commonly with outbuildings, usually with gardens in the courtyard area (Figure 20). The period of their creation in the representative type studied here is limited by the historic events of the first partition of Poland and the end of World War I - both events affecting the buildings' morphology and construction. Kamienica type buildings were historically mainly mixed-use housing and service or single-use housing units. Today they often have changed their original use and have been adapted to other types of accommodation (hotels, hostels, rental apartments) or non-residential service functions. Attics have often been converted to apartments and basements to commercial establishments (typically restaurants and pubs). The kamienica type can be linked to tenement building types of the period not only in Poland but also in neighbouring countries and cities such as Lviv, Vienna, Warsaw, Poznan, Berlin, and Paris because of political and cultural influences.

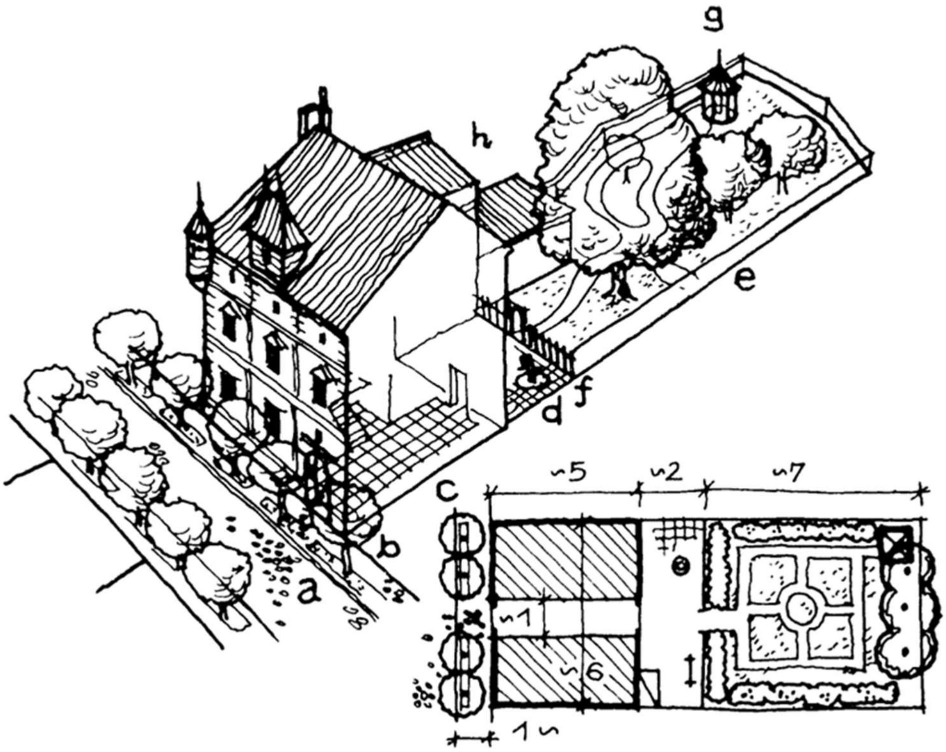


Figure 19. Scheme of a typical plot of kamienica type in Kraków. Source: J. Bogdanowski, 1980

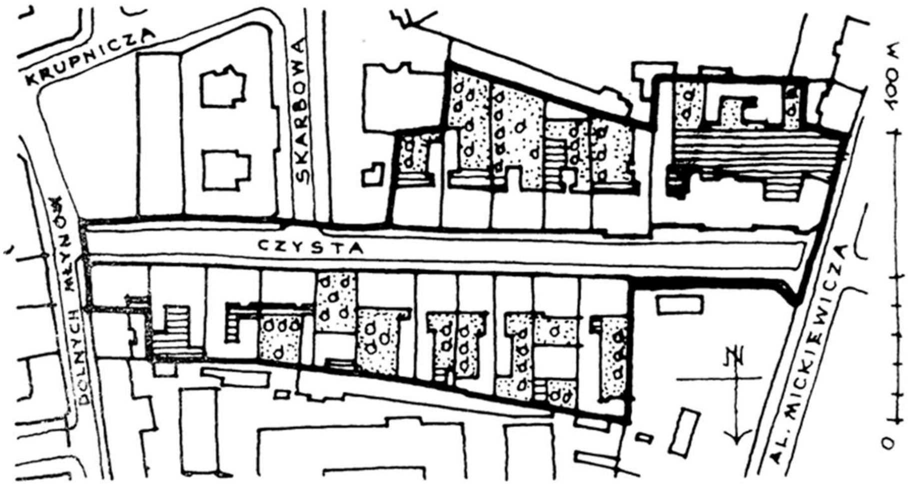


Figure 20. Czysta Street in Kraków (about 1890), an example of typical street from that period, surrounded with kamienica type buildings. Source: J.Bogdanowski, 1980.

According to data extracted from the EU BSO (2024), multifamily houses and apartment blocks realized before 1945 correspond to **3%** of the buildings in Poland. Furthermore, the dwellings corresponding to multifamily houses and apartment blocks realized before 1945 constitute **3,7%** of the dwellings recorded at national level.

Local data related to the city of Krakow and to Poland have been used to estimate the number of kamienicas in Poland. The following data source in GIS format allowed to quantify the number of kamienicas in the city of Krakow:

- *Ewidencja Gruntów i Budynków (EGiB)* (Land and Building Registry database) for Krakow
- *Zespoły i obiekty z terenu Miasta Krakowa wpisane do Rejestru Zabytków* (Complexes and Objects from the City of Krakow listed in the Register of Monuments) from *Wojewódzki Urząd Ochrony Zabytków w Krakowie* (Voivodeship Office for Monument Protection in Krakow)
- *Gminna ewidencja zabytków Krakowa* (Municipal Register of Historical Monuments in Krakow)

Data integration was performed by incorporating historic monuments registry and municipal heritage register data into the EGiB database for buildings under conservation protection. The matching process relied on spatial location, with registry points being matched to EGiB building outlines. A notable limitation is that some heritage registry entries represent entire building complexes rather than individual structures. The Kobierzyn hospital complex illustrates this issue, where a single registry point represents several dozen buildings. Similar unidentified cases may affect the accuracy of building counts within specific typologies. Further verification was conducted using satellite imagery and Google Street View for buildings with unclear typological classification. This verification process helped determine if these structures qualified as tenement houses, villas, or fell outside these categories. Regarding villas, certain buildings were included in the study despite missing construction dates in EGiB, monument register, or municipal heritage records. Their inclusion was justified by historic evidence (including archival maps) documenting the development periods of residential areas in Cichy Kącik, Dębniki, and Salwator.

The study identified 2,307 tenement houses from 1772-1918, representing **1.92%** of all buildings in Krakow. When expanding the stock to include tenement houses built before 1939, the stock size increased to 3,240 (**2.69%** of all buildings in Krakow). The vast majority of kamienica type buildings are located in the current city centre of Kraków (Figure 21). The city building stock from the late 18th, 19th and the beginning of the 20th centuries is substantial, located in the zone of UNESCO-protected urban layout and its buffer zone, and well-preserved despite the 1st and 2nd world wars. The buildings of the former suburban settlements of 1870-1939 have generally remained unchanged or have been super-structured.

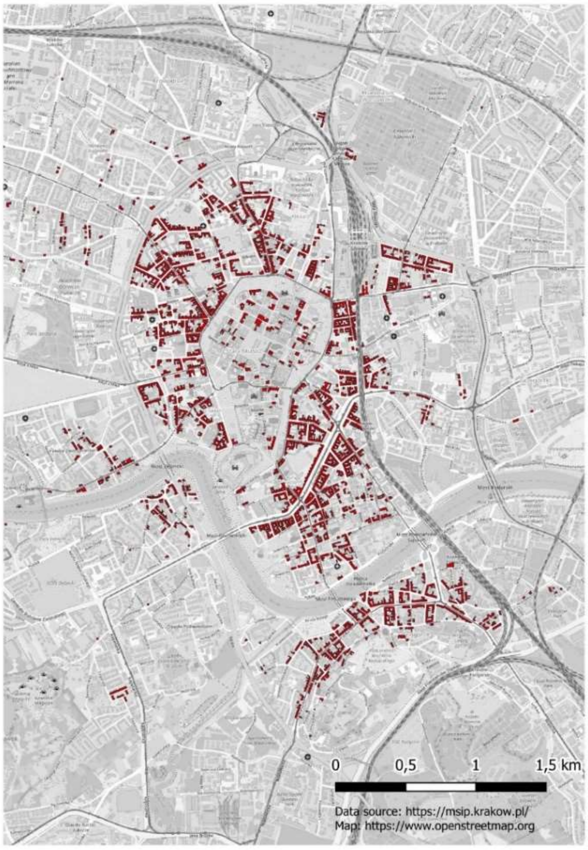


Figure 21. Location of kamienica type buildings in the centre of Kraków. Image: K. Klus.

According to the original functions, the following number of kamienica buildings were identified, distributed into 3 subtypes:

1. The original residential function: multi-family and rarely single residential (often mixed with commercial and craftsman services on the ground floor): 2062 items, including:

    - 2051 houses and tenements (1,70%)
    - 11 urban palaces (0,01%)

2. The original residential function with collective dwelling - the same morphology, period of construction, materials and technologies as subtype 1; also adaptable for multi-family accommodation, and some already adapted: 28 items, incl.:

    - 20 accommodation buildings (0,02%)
    - 7 monastery houses (0,01%)
    - 1 other (0,00%)

3. New function: same period of construction, materials and technology as subtype 1; facilities adaptable for multi-family accommodation, and some already adapted for residential or other functions: 22 items, incl.:

    - 19 administrative and other offices (0,02%)
    - 3 other (0,00%)

Data provided by the Central Statistical Office – Główny Urząd Statystyczny (National Census 2020) allowed to estimate the diffusion of kamienicas at national level by quantifying the numbers of dwellings in Poland by time of construction:

- Dwellings built before 1918 constitute **6.14%** of the total number of apartments in Poland
- Dwellings built between 1918-1944 constitute **8.79%** of the total number of apartments in Poland
- Dwellings built before 1945 constitute **14.94%** of the total number of apartments in Poland

Most of these dwellings correspond to the kamienica typology and to the “willa miejska” (See 3.6). Dwellings in wooden historic buildings are highly uncommon, primarily due to the extensive damage caused during World War II.

Furthermore, the percentage distribution of multifamily buildings in Poland by time of construction was also examined:

- Multifamily buildings built before 1918 constitute **4.83%** of the total number of buildings in Poland
- Multifamily buildings built between 1918-1944 constitute **11.28%** of the total number of buildings in Poland
- Multifamily buildings built before 1945 constitute **16.11%** of the total number of buildings in Poland

Most of the multifamily buildings realized before 1945 in Poland correspond to the kamienica type.

Architectural features

Kamienica buildings can be subdivided into sub-types based on their morphological features and the characteristics of the building plot, including its environmental values (Figure 22).

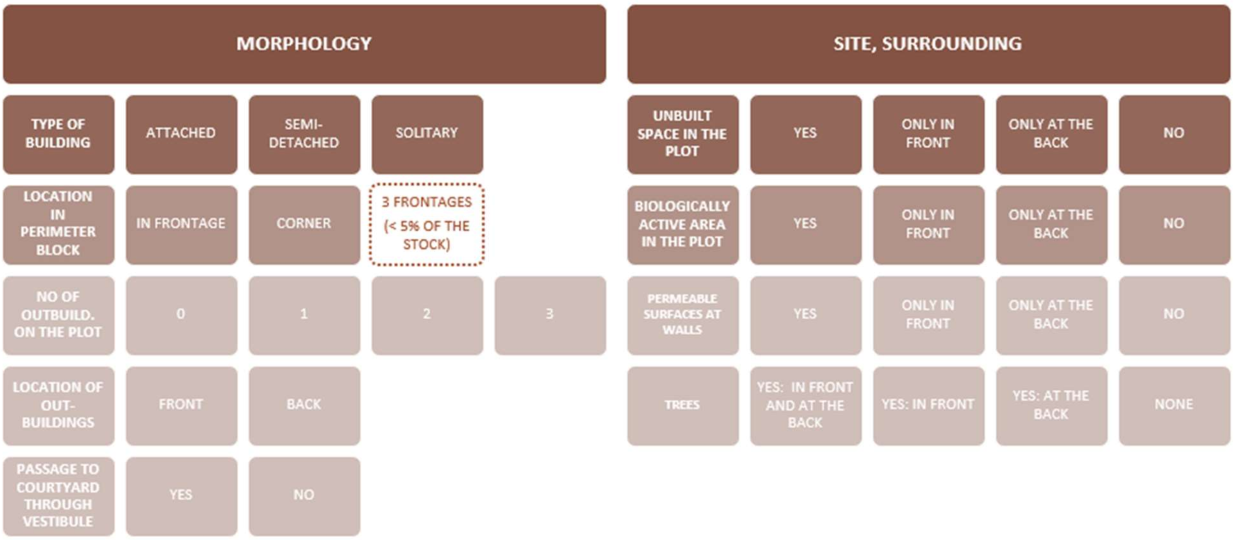


Figure 22. Matrix of identified subtypes of kamienica buildings. Author: E. Szpakowska-Loranc

Morphological subtypes, determined by the number of outbuildings, were dependent on plot widths and linked to foreign trends in the construction of multifamily houses (Figure 23). The subtypes included:

- subtype without outbuildings (top drawing)
- subtype with 1-3 outbuildings built along the edges of the site (middle drawing)

- subtype with outbuildings in the front – adjacent to the attached perpendicularly to the front street facade (bottom left drawing)
- subtype with outbuildings attached perpendicularly to the building's back elevation and dividing plots into two or more smaller courtyards (bottom right drawing)

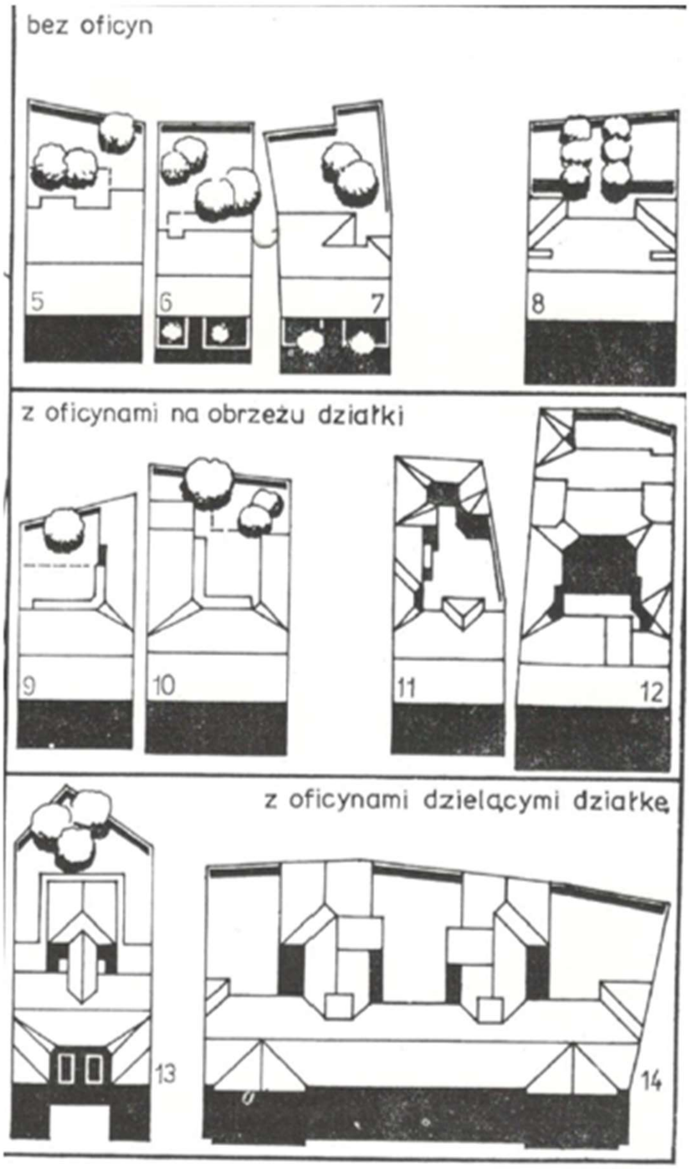


Figure 23. Drawing presenting mophological sub-types of the kamienica type, Source:: Frysztak,1984.

Buildings with one or two outbuildings were constructed on plots of land with corresponding widths: 12,5-15 m for one outbuilding, and 17,5-30 m for two outbuildings. They were inspired by Berlin tendencies of dense multi-residential architecture, whereas outbuildings in front were based on Paris tendencies; green courtyards on the plots were inspired by Vienna influences.

Materials and constructive systems used to build kamienicas are consistent. The main construction elements were originally realized as follows:

- Walls and foundations. The constructive system for the typology was based on the solid clay brick masonry walls, sometimes plastered and with rustications. Typical 19th-century Central European tenements and townhouses external wall use the block bond and are around 50 cm thick. The foundations are brick or stone or mixed, often cellar had earthen floors.
- Roof. Typical houses had pitched roofs with wooden roof truss's structure. The roof finishing were usually metal sheets or roof tiles.
- Floor. Structure involved arched brick jack-arch ceiling on steel I-beams with wooden flooring on sawdust and clay. In a small number of cases, individual ceilings were remodelled into reinforced concrete slabs with screed and tiled flooring. Basement ceilings were brick barrel vaults with sawdust and clay infill.
- Windows were usually box-type/casement wooden windows.

3.5.2. Defining features of the typology

Table 11. Defining features of Polish typology "kamienica".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	• *1750-1850* • *1850-1920* • *1920-1945*
	2	Climate	*Cfb Köppen-Geiger climate class*
	3	Original use	*Mixed*
	4	Context	*Urban*
Geometrical parameters	5	Footprint shape	*L -shape*
	6	Footprint area	*Medium (150<>300 m^2)*
	7	Floor surface area (range)	*Medium (200<>1000 m^2)*
	8	Situation	*Infill (adjoining buildings on two or more sides)*
Architectural qualities	9	Architectural Style	*NA*
	10	Envelope construction	• *Solid brick walls (~50 cm-thick)* • *Pitched roof, wooden truss and decking, metal sheets – standing seam* • *Floor on grade: earthen floor* • *Box-type/casement windows with internal and external leaves, timber frame, single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Internal circulation* • *Direct light, partially shaded by surrounding buildings* • *Compactness* • *Natural ventilation* • *Solar shading* • *Vegetation*
Heritage attribute	13	Heritage attributes to be preserved	• *Windows* • *Doors*

3.5.3. Variable features of the typology

Table 12. Variable features of Polish typology "kamienica".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	*Back yard*
	16	Buffer spaces	*None*
Heritage values	17	Typical level of protection	*Medium (National interest)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*1*
	20	Integrity (1:max-5:min)	*1*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Architectural* • *Historic* • *Urban Planning*

3.5.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 24 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. The exterior walls of this typology are built of solid bricks. The U-value of the exterior wall of the ground floor of the demonstrator building has been included to identify the range. The performance of this element is in line with all data collected for multifamily buildings realized in Poland before 1945. Therefore, based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,00-1,60 W/(m²*K).**

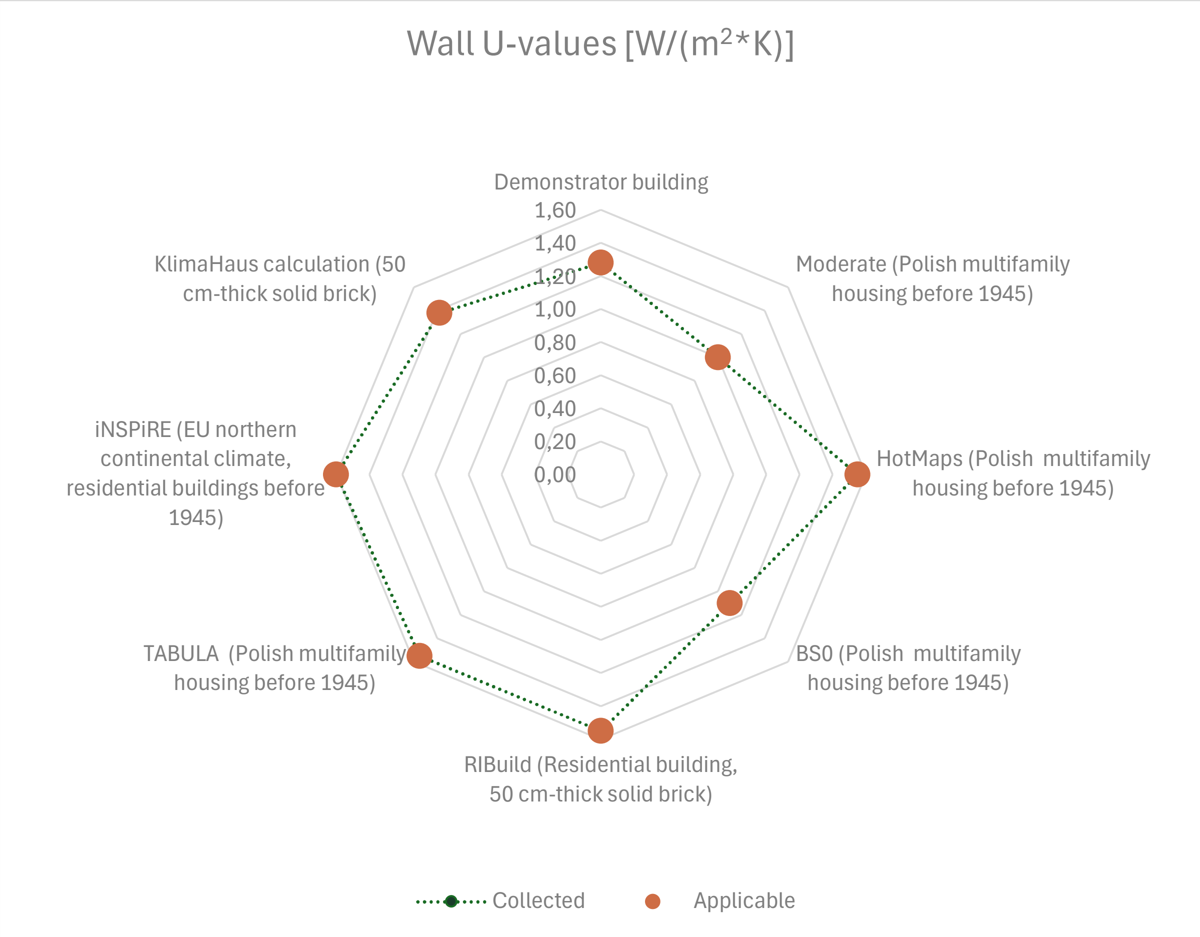


Figure 24. U-values identified for walls of multifamily buildings with similar features to the typology "kamienica"

Roof

Figure 25 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value of the roof of the demonstrator building is higher than the ones collected from other sources. It has been considered to increase the upper limit of the range. The U-value range generated for the roof of this typology is **0,90-2,70 W/(m²*K).** This range is quite wide because of the variability of the structural layers within the typology.

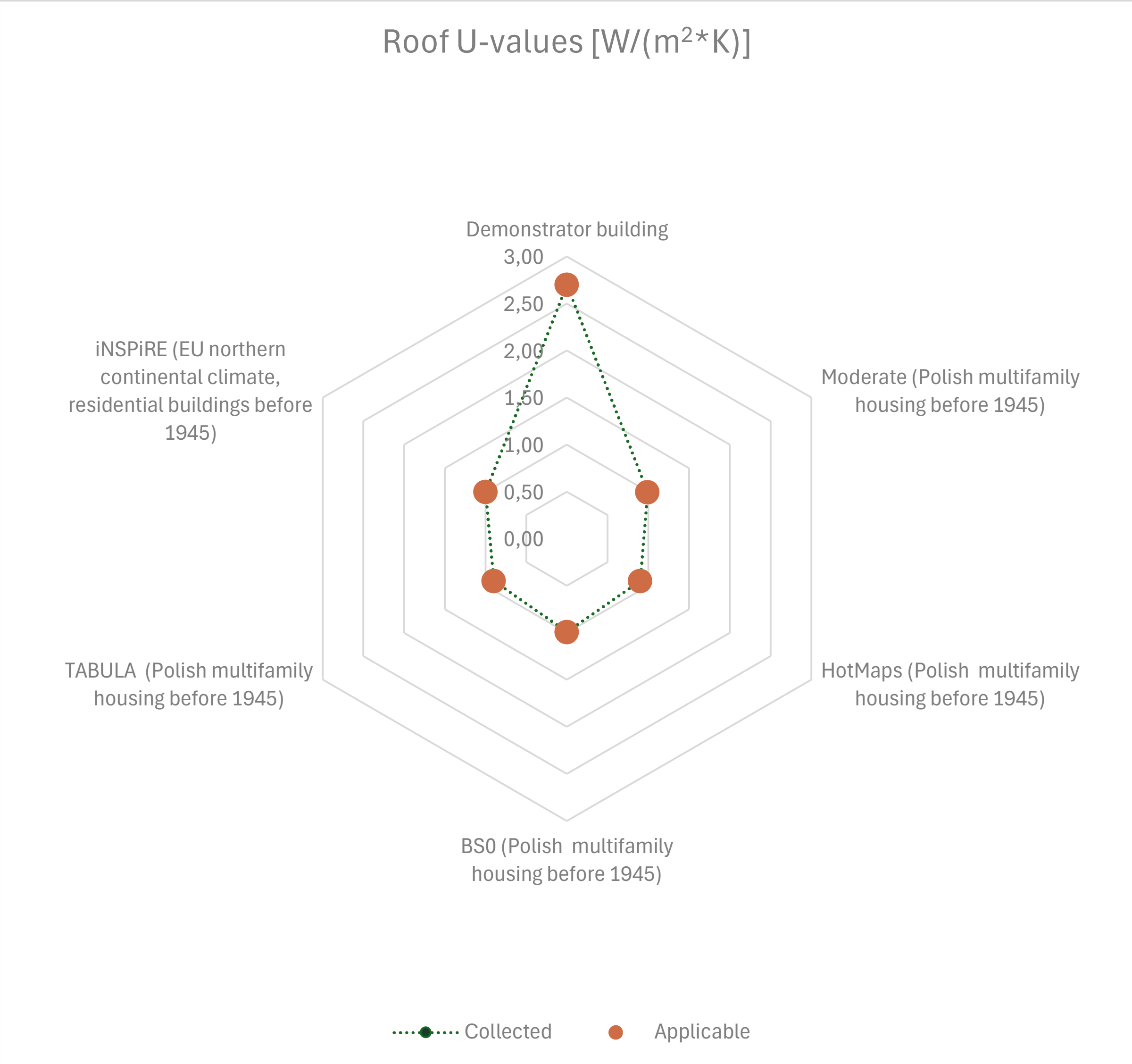


Figure 25. U-values identified for roofs of multifamily buildings with similar features to the typology "kamienica".

Floor

Figure 26 provides an overview of the data collected to define a U-value range for the floor of this typology. The original floor construction associated with this typology is built of brick barrel vaults above a basement. This structure corresponds to the demonstrator building; therefore, the U-value of its ground floor slab has been considered to decrease the lower limit of the range and resulting from collected data and exclude higher values (corresponding to a different type of construction). The range identified for the floor of this typology is **0,72-1,60 W/(m²*K).**

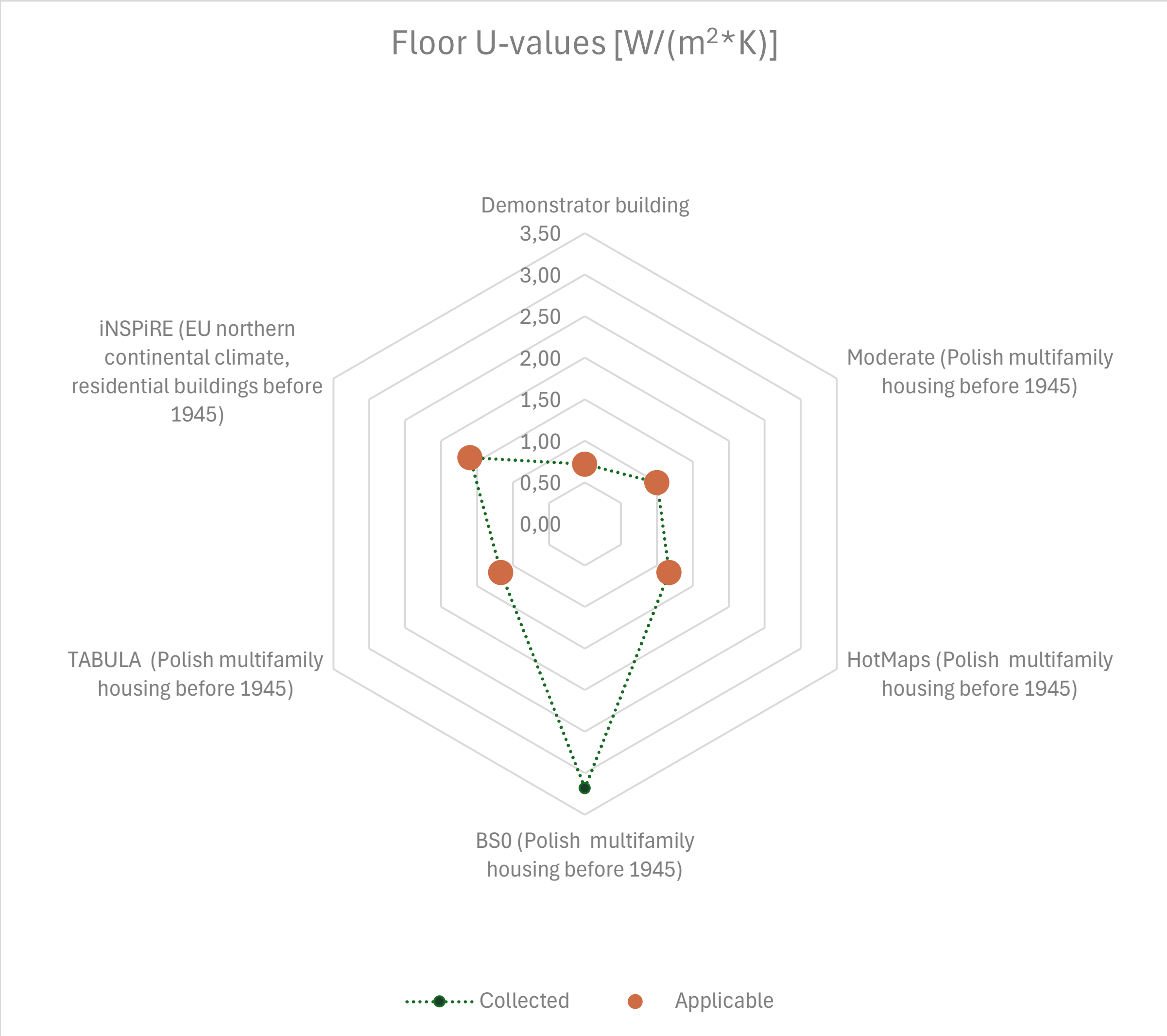


Figure 26. U-values identified for floors of multifamily buildings with similar features to the typology "kamienica".

Windows

Figure 27 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. Since the standard original windows of the demonstrator buildings have been upgraded or replaced, the U-value range for the original typological element has been generated based on the data collected from other sources: **3,18-5,00 W/(m²*K).**

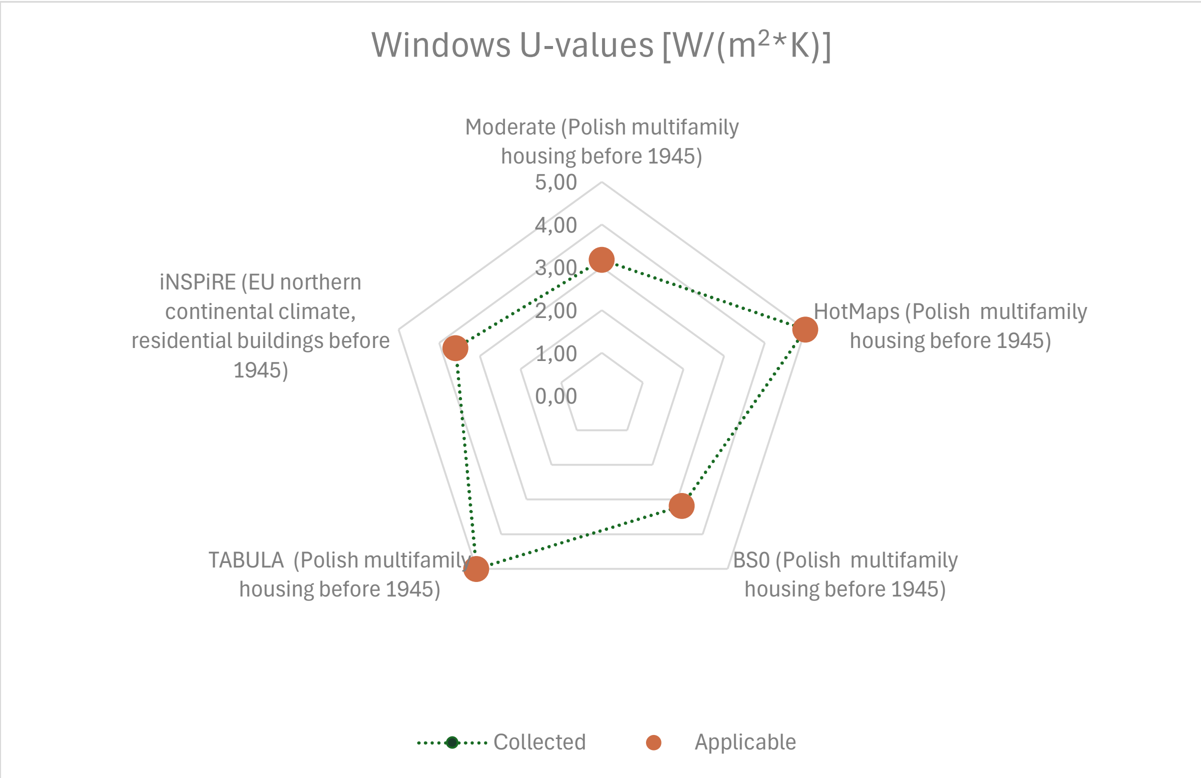


Figure 27. U-values identified for windows of multifamily buildings with similar features to the typology "kamienica".

Energy demand and consumption for heating and cooling

Figure 28 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. No range has been defined for cooling demand as the data from the two sources identified coincided. The ranges identified for energy demand are the following:

- Heating: **126-187 kWh/m² year**
- Cooling: **36 kWh/m² year**
- Heating and cooling: **156-208 kWh/m² year**

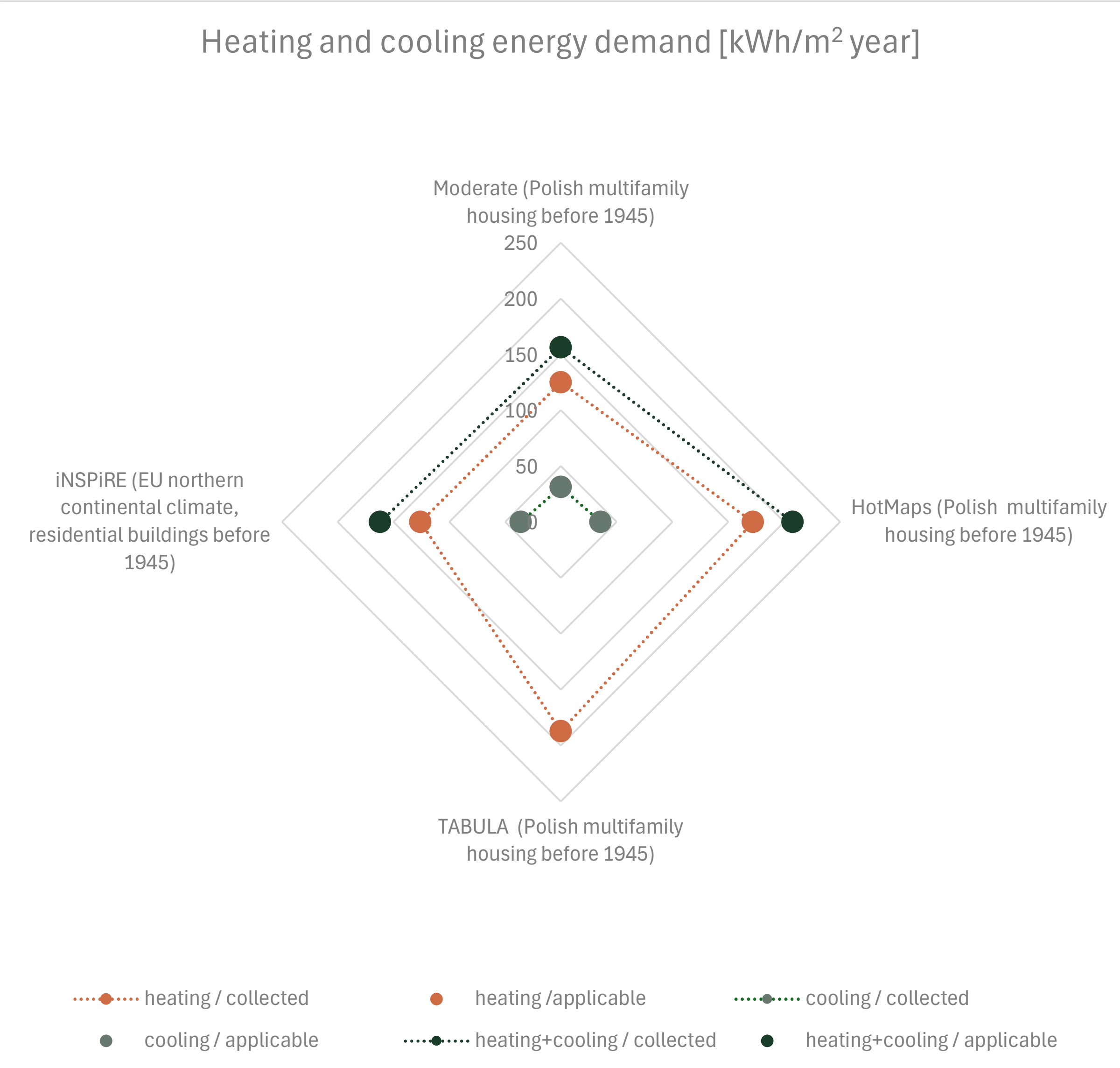


Figure 28. Energy demand data for heating and cooling identified for multifamily buildings with similar features to the typology "kamienica".

Hotmaps (2020) and Moderate (2022) datasets also provided quantification of the energy average consumption for heating and cooling for Polish multifamily housing buildings realized before 1945. The ranges identified for energy consumption from these sources are the following:

- Heating: **145-199 kWh/m^2 year**
- Cooling: **3-4 kWh/m^2 year**
- Heating and cooling: **149-203 kWh/m^2 year**

3.6. Willa miejska: Polish garden-city/urban villa (1900-1945)

3.6.1 Contextualization of the typology

Origin and diffusion

The turn of the century, inspired by the garden-city Howard's concept brought new, slowly introduced urban and architectural designs of urban villa's estates on the terrain of contemporary Poland. This impulse was reinforced by political changes. The year 1918 brought the long-awaited freedom of the Republic after 123 years of partitions, but also the challenges of rebuilding the state. In addition to merging lands torn apart for decades between the partitioning powers, investments in progressive infrastructure were necessary: administrative buildings, schools, hospitals, and housing estates. Many Polish cities implemented forward-thinking projects that remain examples of functional spatial development to this day.

In the Second Polish Republic (1918-1939), cities whose development had been held back by restrictions resulting from their military function gained opportunities to shape modern estates on lands freed from functions imposed on them for decades. The liquidation of fortifications created opportunities for spatial development of many cities, including Krakow and Warsaw. Plans for developing the outskirts of Krakow appeared even before 1914, which was associated with expanding the city area after lifting some restrictions in the Krakow Fortress area. There, as early as 1923, the Officers' Estate was built on grounds only 2.5 km from the Main Market Square. Its creation was the result of the activity of the Officials' Settlement Society and the Officers' Housing Cooperative. Such housing cooperatives were aiming to implement housing construction of a specific standard, corresponding to the aspirations of the then middle class. Such actions were undertaken after World War I in many Polish cities, resulting in the creation of housing colonies in Warsaw, Łódź, and Lviv, among others.

Villas and mansions with decorative gardens belonged to representatives of the upper middle class—higher officials, university professors, people practicing liberal professions, and other wealthy townspeople (Figure 29). These buildings were typically two or more stories high and were carefully designed and constructed, showcasing exceptional craftsmanship and style (Figure 30). A distinctive layout of plot development emerged: the entrance area was positioned on the side (rather than axially), the main entrance to the house was in its side elevation, and behind the representative section lay a small utility courtyard. The remaining part of the plot was occupied by a decorative garden, which sometimes included a vegetable garden section (Figure 31).

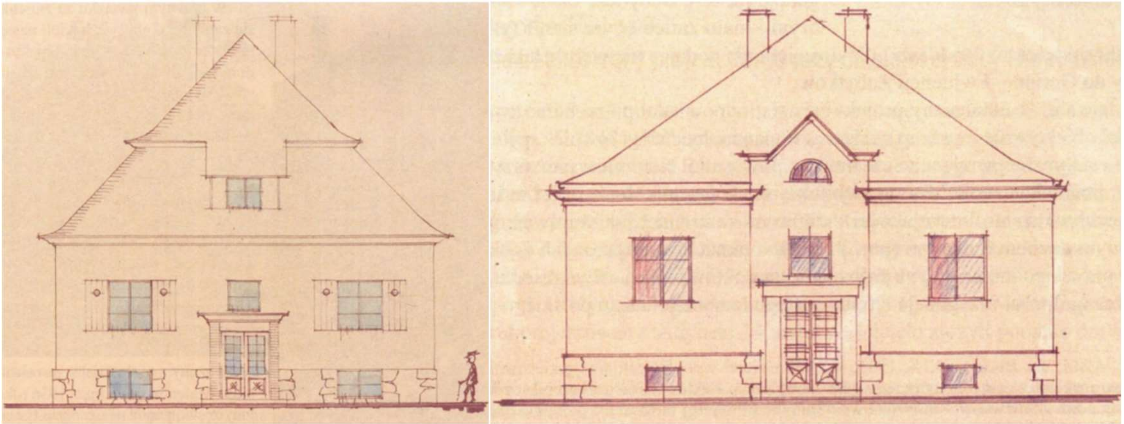


Figure 29. Houses of the Official Neighbourhood in Krakow, Olsza district 1924-1960. Source: Motak, 2016.

Figure 30. Salwator urban villa estate in Kraków, Zwierzyniec district, an early 20th century garden city. Aerial photo: P. Mazur 2024.

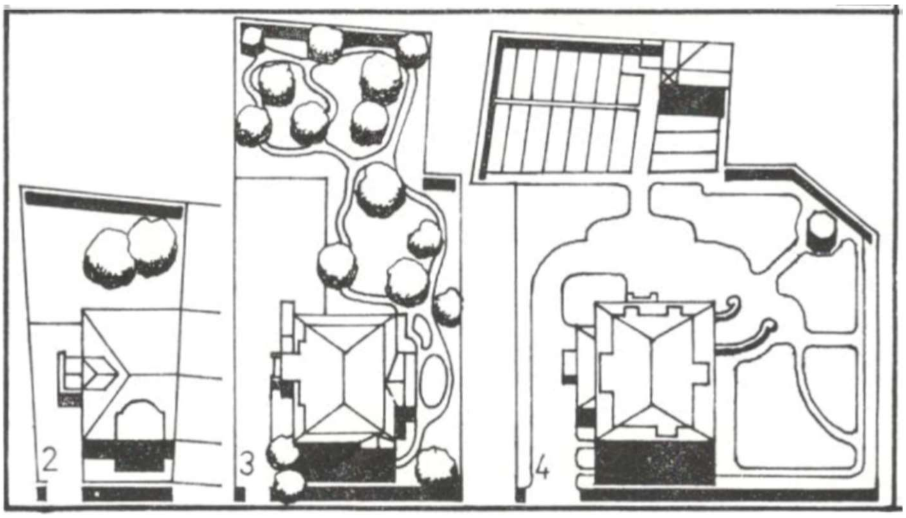


Figure 31. Morphological subtypes of Krakow's residential fabric at the turn of the 19th/20th centuries, corresponding to the urban villa type, source: Frysztak, 1984.

According to data extracted from the EU BSO (2024), single family houses realized before 1945 correspond to **9,7%** of the buildings in Poland. Furthermore, the dwellings corresponding to single family houses realized before 1945 constitute **9,9%** of the dwellings recorded at national level.

As for the kamienica typology, the city of Krakow has been examined to study the diffusion of the typology in Poland. The same data and methodology were used to estimate the number of urban garden-city/urban villa. The study identified 1,183 villas from 1910-1952, representing **0.98%** of all buildings in Krakow (Figure 32).

As already mentioned in the description of the kamienica typology, according to the data provided by the Central Statistical Office – *Główny Urząd Statystyczny* (National Census 2020), dwellings built before 1945 constitute **14.94%** of the Polish buildings stock. Most of these apartments correspond to the kamienica typology and to the garden-city/urban villa.

Figure 32. Location of villa buildings in the centre of Kraków. Image: K. Klus.

Architectural features

The earliest examples, appearing from 1909 onwards, combined historicizing, eclectic styles with modest Art Nouveau elements. Following Poland's independence in 1918, the manor house style gained prominence, integrating traditional Polish architectural elements such as broken roofs, dormers, quasi-porticos, columns, and triangular gables. This style held particular significance in the context of nation-building, as it connected the newly liberated society with the noble traditions of a free and sovereign state. While the 1930s saw a gradual shift toward international style and functionalism, traditional influences persisted, particularly in decorative arts where folk motifs merged with geometric forms to create a distinctly Polish variant of art déco.

Villa roofs are characterized by a significant slope, usually above 16°. They are a common feature in climatic zones with high rainfall and snowfall, such as Poland, because they allow for efficient drainage of rainwater and snow sliding. These roofs also enable the use of attic space as additional living area. Characteristic features include a wooden roof structure (roof truss), most often with rafters supported by masonry. The roofs take various forms including hipped, Polish broken roof (a distinctive double-pitched design like mansard), and often incorporate decorative elements like dormers and gables. They typically feature large chimneys, a legacy of traditional heating methods using stoves during cold seasons.

The villas feature several traditional bioclimatic solutions including high ceilings (3-4 m clear height) and large windows for natural ventilation and lighting, as well as thick masonry walls (40-60 cm) providing thermal mass. The buildings incorporate passive climate control through deep eaves, verandas, and carefully placed windows responding to solar orientation, while basements and attics serve as thermal buffer zones. Natural comfort is enhanced by cross-ventilation possibilities, traditional double windows, and the building's integration with its garden setting, which contributes to the microclimate regulation.

3.6.2. Defining features of the typology

Table 13. Defining features of Polish typology "willa miejska".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1920-1945*
	2	Climate	*Cfb Köppen-Geiger climate class*
	3	Original use	*Residential*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	*O-shape (i.e., square/circle-like)* *I-shape (i.e., rectangular)*
	6	Footprint area (range)	*Small (<150 m²)* *Medium (150<>300 m²)*
	7	Floor surface area (range)	*Small (<200 m²)*
	8	Situation	*Detached (stand-alone building)*
Architectural characteristics	9	Architectural Style	*Historicist, early Art Nouveau, Polish Manor Revival, Eclectic, Art Deco*
	10	Envelope construction	• *Solid brick walls (~50 cm-thick)* • *High hipped roof with dormers, timber structure, ceramic tile roofing, occasionally seam metal roofing* • *Steel and brick flat arches, timber beam* • *Box-type/casement wooden windows, single glazing*
	11	WWR (range)	*Multiple choice:* • *Small (<20%)* • *Medium (20%<>30%)* • *Large (>30%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Symmetrical layout, compact floor plan, usually 2 floors, central entrance portico (columned porch), integration with surrounding garden, veranda or terrace on private garden side* • *Good natural lighting through multiple windows* • *Steep roofs, garden greenery*
Heritage attributes	13	Heritage attributes to be preserved	• *Roof shape – high hipped roof with dormers* • *Representative portico with columns* • *Symmetrical facade design* • *Decorative cornices, plaster mouldings and details* • *Property boundaries and integration with urban context* • *Original garden layout*

3.6.3. Variable features of the typology

Table 14. Variable features of Polish typology "willa miejska".

Type	Nr	Feature	Definition of the feature
Occupancy	13	Occupancy	*Permanent*
Spatial situation	14	Surroundings	• *Front yard* • *Back yard*
	15	Buffer spaces	• *Attic* • *Basement*
Heritage values	16	Typical level of protection	• *Medium (National interest)* • *Low (Local interest, partial protection)*
	17	Conservation area	• *Yes*
	18	Authenticity (1:max-5:min)	*2*
	19	Integrity (1:max-5:min)	*3*
	20	Rarity (1:max-5:min)	*5*
	21	Representativeness (1:max-5:min)	*1*
	22	Interests	• *Aesthetic* • *Architectural* • *Historic* • *Urban Planning* • *Memorial* • *Landscape*

3.6.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 33 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of solid bricks. Therefore, based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,10-1,55 W/(m²*K).**

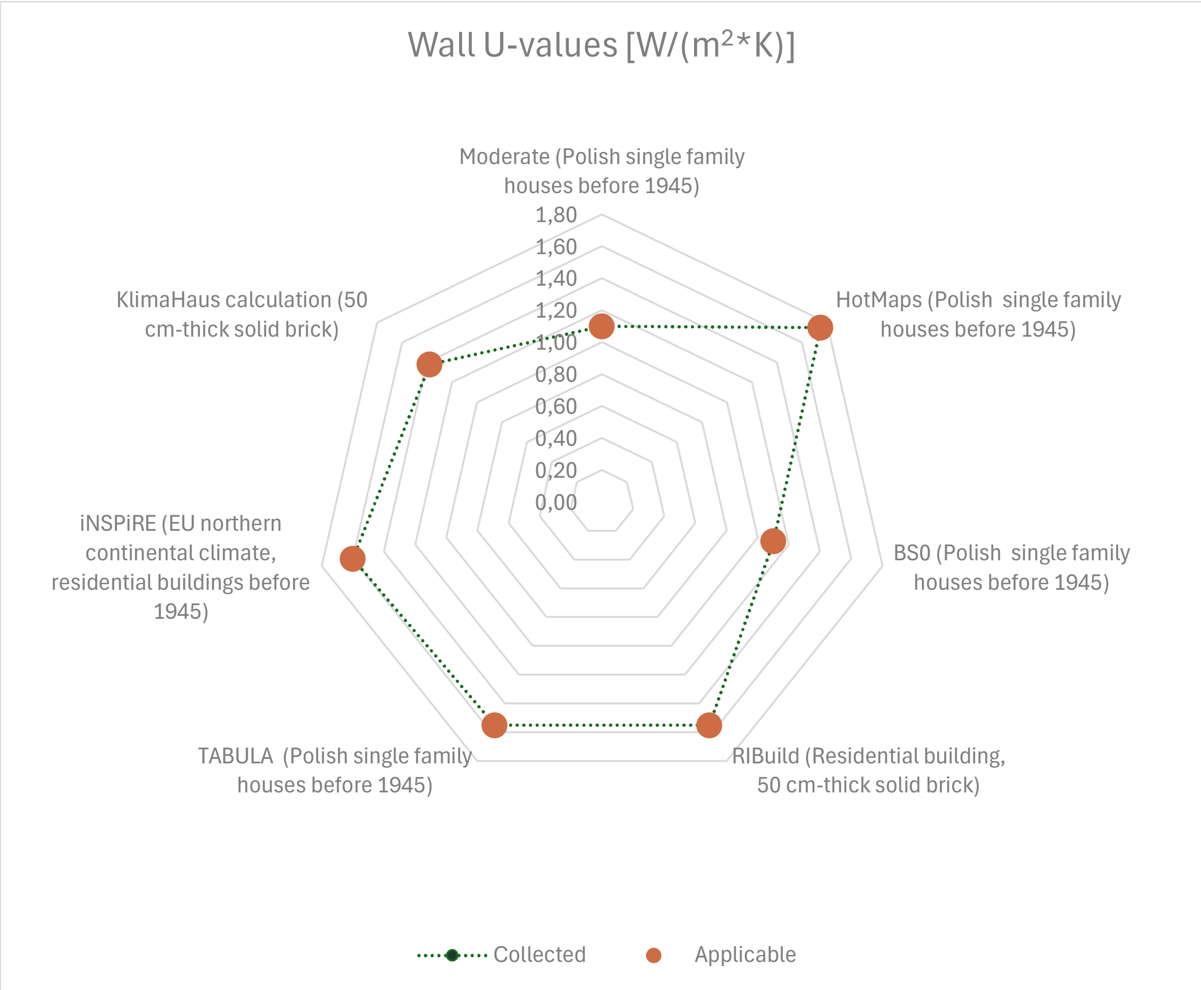


Figure 33. U-values identified for walls of residential buildings with similar features to the typology "willa miejska"

Roof

Figure 34 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value range generated for the roof of this typology is **0,70-1,10 W/(m²*K).**

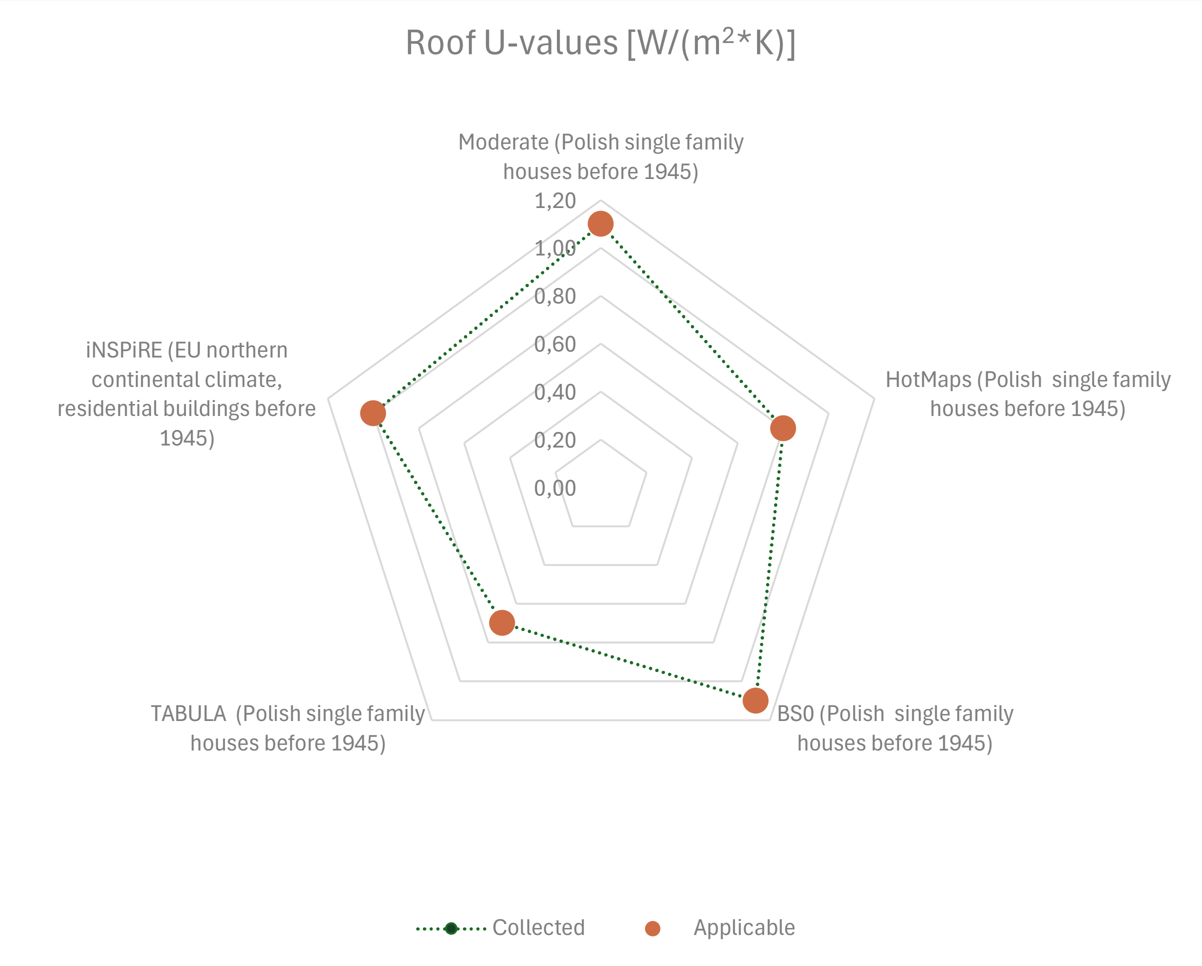


Figure 34. U-values identified for roofs of residential buildings with similar features to the typology "willa miejska".

Floor

Figure 35 provides an overview of the data collected to define a U-value range for the floor of this typology. The original floor construction associated with this typology is built of brick structure above a basement. This structure corresponds to the ones of the demonstrator building of the previous typology; therefore, the U-value of its ground floor slab has been considered to decrease the lower limit of the range. The range identified for the floor of this typology is **0,72-2,20 W/(m²*K).**

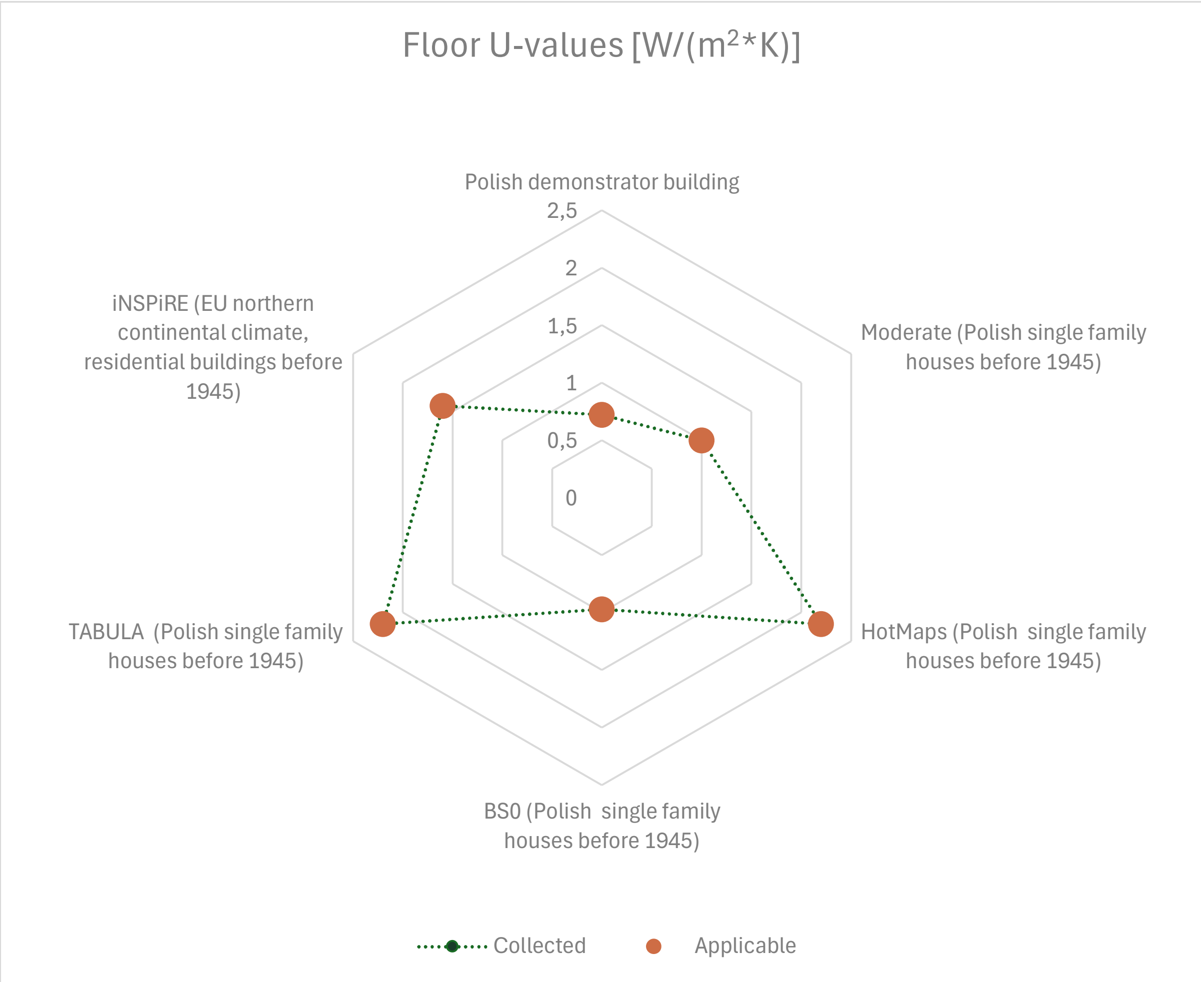


Figure 35. U-values identified for floors of residential buildings with similar features to the typology "willa miejska".

Windows

Figure 36 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. The U-value range for the original typological element corresponds to **3,18- 5,00 W/(m²*K).**

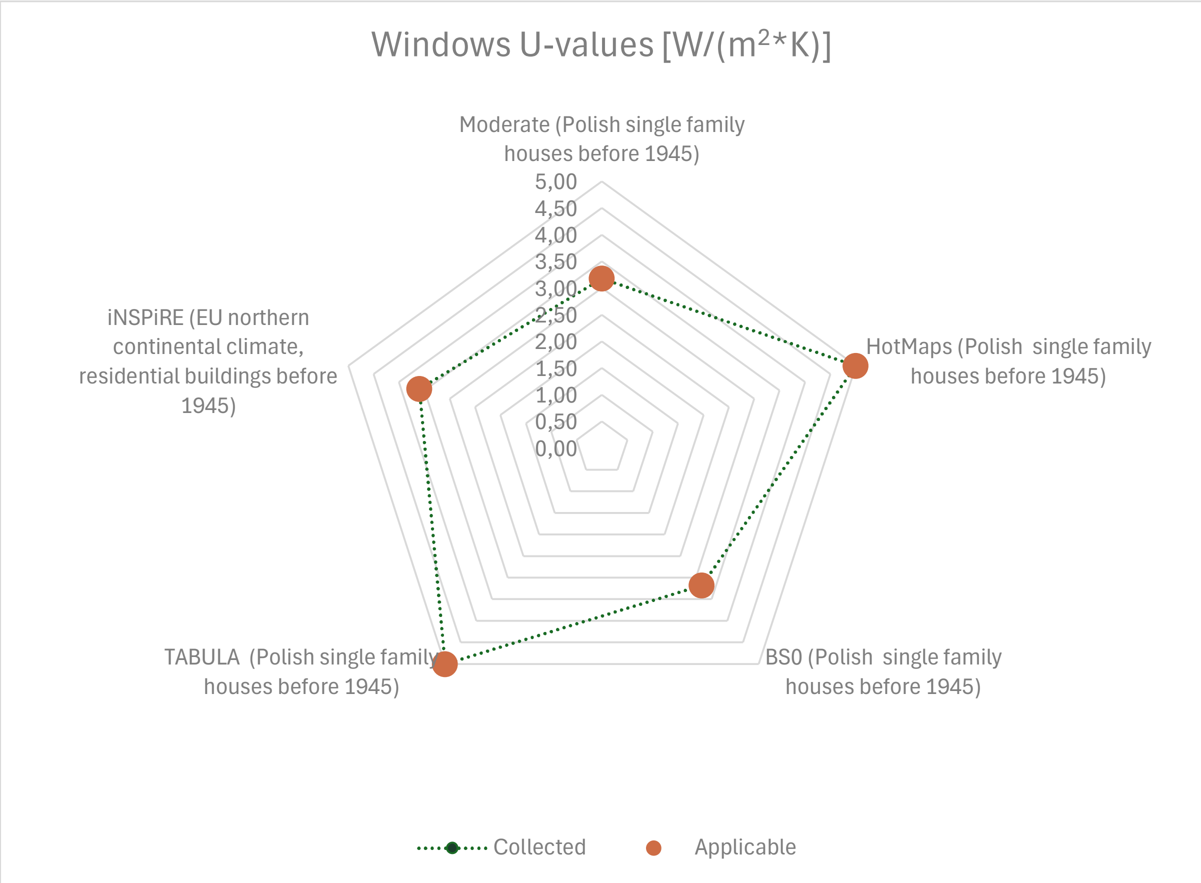


Figure 36. U-values identified for windows of residential buildings with similar features to the typology "willa miejska".

Energy demand and consumption for heating and cooling

Figure 37 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **126-313 kWh/m² year**
- Cooling: **32-36 kWh/m² year**
- Heating and cooling: **162-345 kWh/m² year**

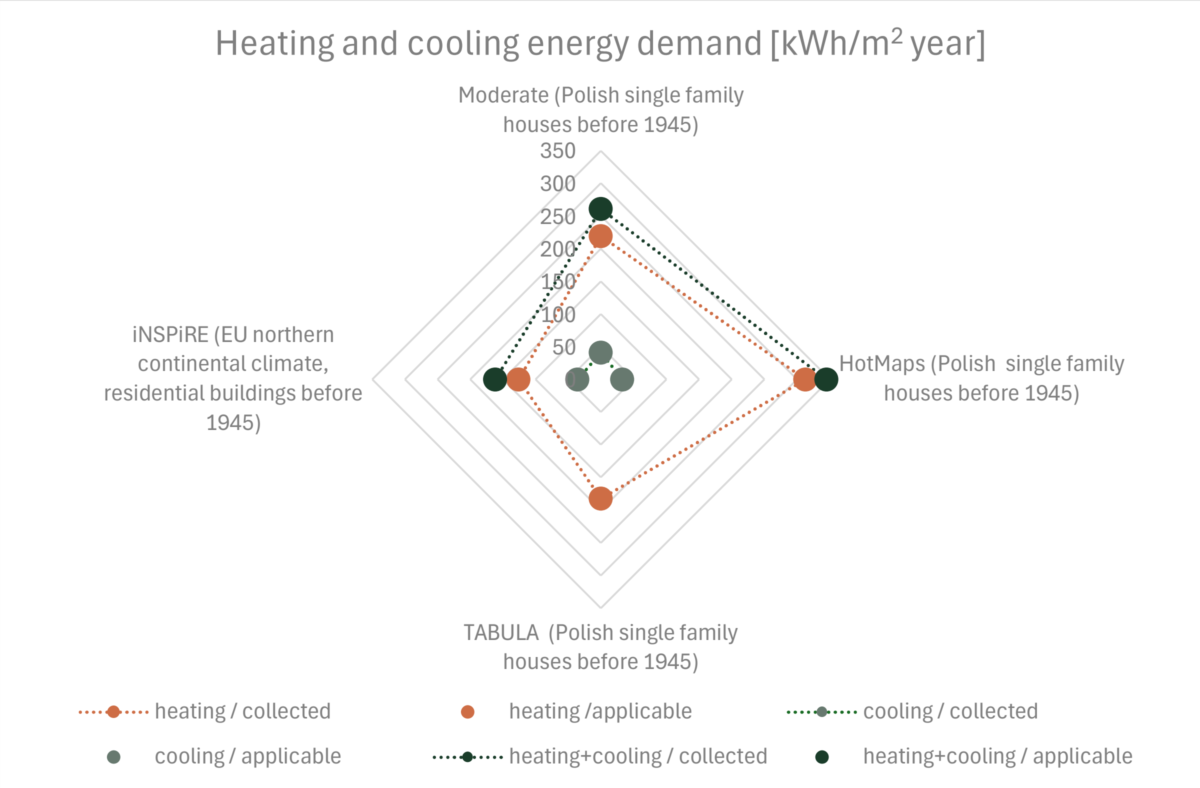


Figure 37. Energy demand data for heating and cooling identified for residential buildings with similar features to the typology "willa miejska".

Hotmaps (2020) and Moderate (2022) datasets also provided quantification of the energy average consumption for heating and cooling for Polish single-family houses realized before 1945. The ranges identified for energy consumption from these sources are the following:

- Heating: **256-364 kWh/m² year**
- Cooling: **4-5 kWh/m² year**
- Heating and cooling: **260-368 kWh/m² year**

3.7. Monumentalbyggnad: Swedish monumental public building (1850-1920)

3.7.1. Contextualization of the typology

Origin and diffusion

“Monumentalbyggnad” is the typology defined for the demonstrator building located in Sweden (Figure 38). In 19th-century Sweden, the rise of new public buildings emerged as a direct response to sweeping social reforms and a growing need for accessible public services. During this period, Sweden, like much of Europe, was transitioning from a primarily agrarian society to one increasingly influenced by industrialization and modernization. This transformation brought about new administrative and educational needs, leading to a wave of construction projects aimed at creating spaces for public governance, education, and community life.

Figure 38. Swedish demonstrator building. Jacob Wilhelm Gerss, Domkapitelhuset Linköping, 1830. Photo: White Arkitekter

Educational Buildings: In the early 19th century, Sweden recognized the importance of education in fostering an informed citizenry, which was essential to support its modernizing society. The establishment of "folkskolan" (public elementary school) in 1842 marked a landmark reform, requiring each parish to establish and maintain a primary school. This mandate led to the construction of purpose-built schoolhouses throughout the country, reflecting the architectural styles of the time. These school buildings often showcased neoclassical elements, symbolizing enlightenment ideals of clarity, order, and rationality, as they aimed to promote a literate and skilled population.

Administrative Buildings: The period also saw a surge in new government buildings as Sweden modernized its public administration. County administration buildings, courthouses, and municipal offices were built to handle the increasing complexity of governmental functions. These buildings provided a formalized space where administrative work could be conducted, enabling the government to better manage societal needs in urban planning, public health, and welfare. Architecturally, many of these buildings followed styles that conveyed stability and authority—often drawing from neoclassical and later eclectic styles, which were seen as fitting symbols for a modernizing state.

Other examples for this typology include well-known buildings such as: Norra Real (Stockholm, 1890–1891), Malmö Town Hall (Malmö, 1540s, rebuilt in the 19th century), Landskrona Town Hall (Landskrona, 1882–1884), The Royal Library (Stockholm, 1871–1877), Gothenburg Town Hall (Gothenburg, 1816–1817, extended mid-19th century), Östra Real (Stockholm, 1895–1898), Katharina Västra School (Stockholm, 1856) (Figure 39).

According to data extracted from the EU BSO (2024), service buildings realized before 1945 correspond to **0,9%** of the buildings in Sweden.

Figure 39. Johan Fredrik Åbom, Katharina Västra Skola, Stockholm, 1830. Photo: Holger Ellgaard, Creative Commons Attribution-Share Alike 3.0 Unported license.

Architectural features

Brick was a dominant building material for public buildings in the 19th century, especially for schools, town halls, and administrative buildings. It was chosen for its durability, fire resistance, and the possibility of creating detailed facades. Brick walls were usually plastered. Many of these buildings exhibit a Neo-Renaissance style, where brick was combined with decorative elements in stone and stucco to create a monumental and formal atmosphere.

Public buildings were usually designed with a simple rectangular shape to ensure effective indoor circulation. The internal floors are partly a wooden construction and partly vaulted (staircase). Roofs were built of wooden trusses and finished with dark slates.

3.7.2. Defining features of the typology

Table 15. Defining features of Swedish typology "Monumentalbyggnad".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	• *1750-1850* • *1850-1920*
	2	Climate	*Dfb Köppen-Geiger climate class*
	3	Original use	*Service*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	*Large (>300 m^2)*
	7	Floor surface area (range)	*Large (>1000 m^2)*
	8	Situation	*Detached (stand-alone building)*
Architectural characteristics	9	Architectural Style	*Neo-renaissance*
	10	Envelope construction	• *Solid brick walls (50-70 cm-thick), plastered* • *Tilted roof, wooden beams, dark slates* • *Slabs: Wooden beams with a sub floor that supports a filling of sawdust.* • *Coupled windows, wooden frame, single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Internal circulation* • *Good natural lighting*
Heritage attributes	13	Heritage attributes to be preserved	• *Façade design, material and proportion* • *Roof shape and finishing*

3.7.3. Variable features of the typology

Table 16. Variable features of Swedish typology "Monumentalbyggnad".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	• *Front yard* • *Back yard*
	16	Buffer spaces	*None*
Heritage values	17	Typical level of protection	*Medium (National interest)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*2*
	20	Integrity (1:max-5:min)	*3*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Architectural* • *Historic* • *Urban Planning*

3.7.4. Energy performance of the typology

Performance of building envelope elements

When available in the datasets, data about performance of school and office buildings have been selected to identify the ranges. Otherwise, data about non-residential buildings have been used.

Walls

Figure 40 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of solid bricks, with a thickness ranging from 50 to 70 cm. U-values from RIBuild (2020) have been interpolated to obtain value that match the thickness of the walls of the typology. Therefore, based on the data applicable to this construction, the U-value range generated for the walls of this typology is **0,60-1,31 W/(m²*K).**

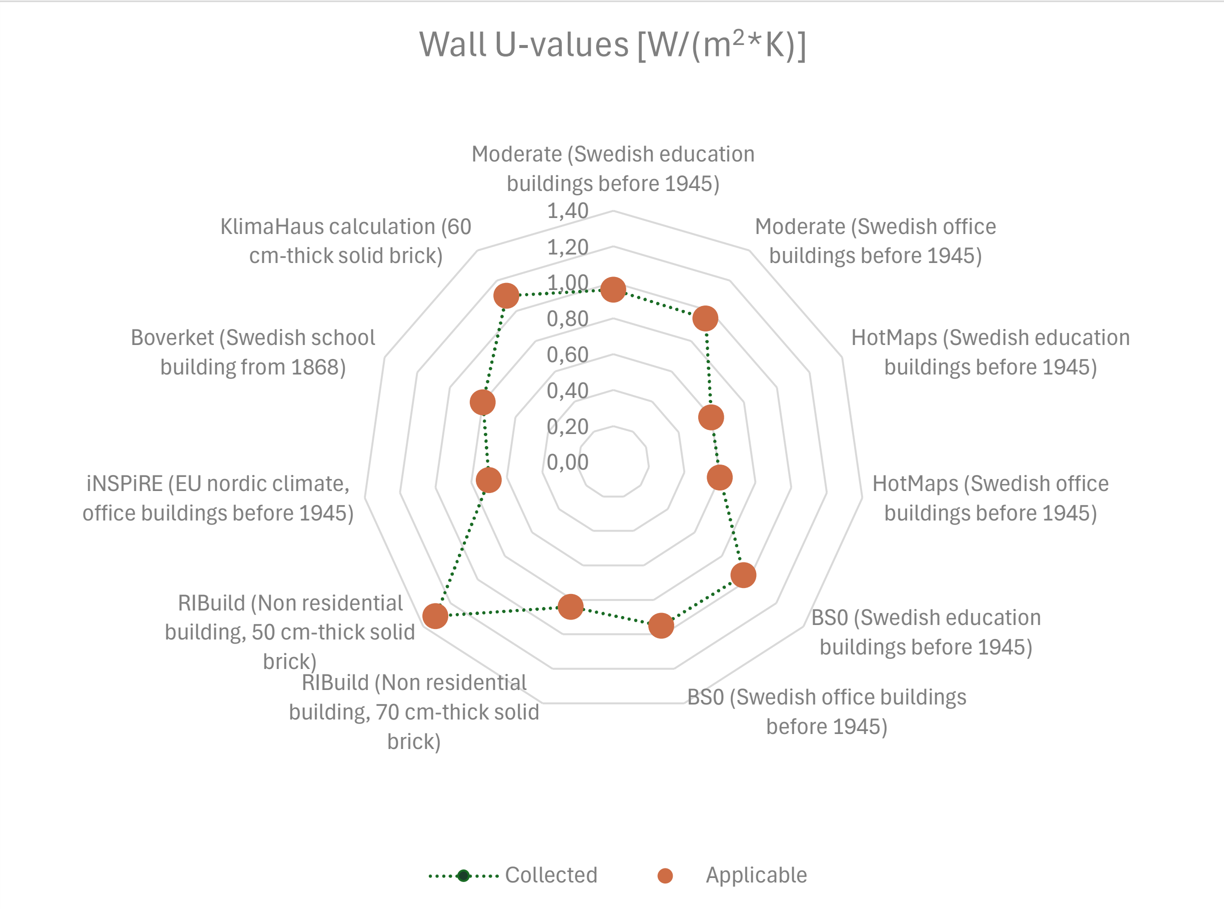


Figure 40. U-values identified for walls of buildings with similar features to the typology “Monumentalbyggnad”.

Roof

Figure 41 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-values identified from Hotmaps for school and offices realized before 1945 have been excluded from the ranges because they represent the typical performance of retrofitted roofs. The U-value range generated for the roof of this typology is **0,40-0,77 W/(m²*K).**

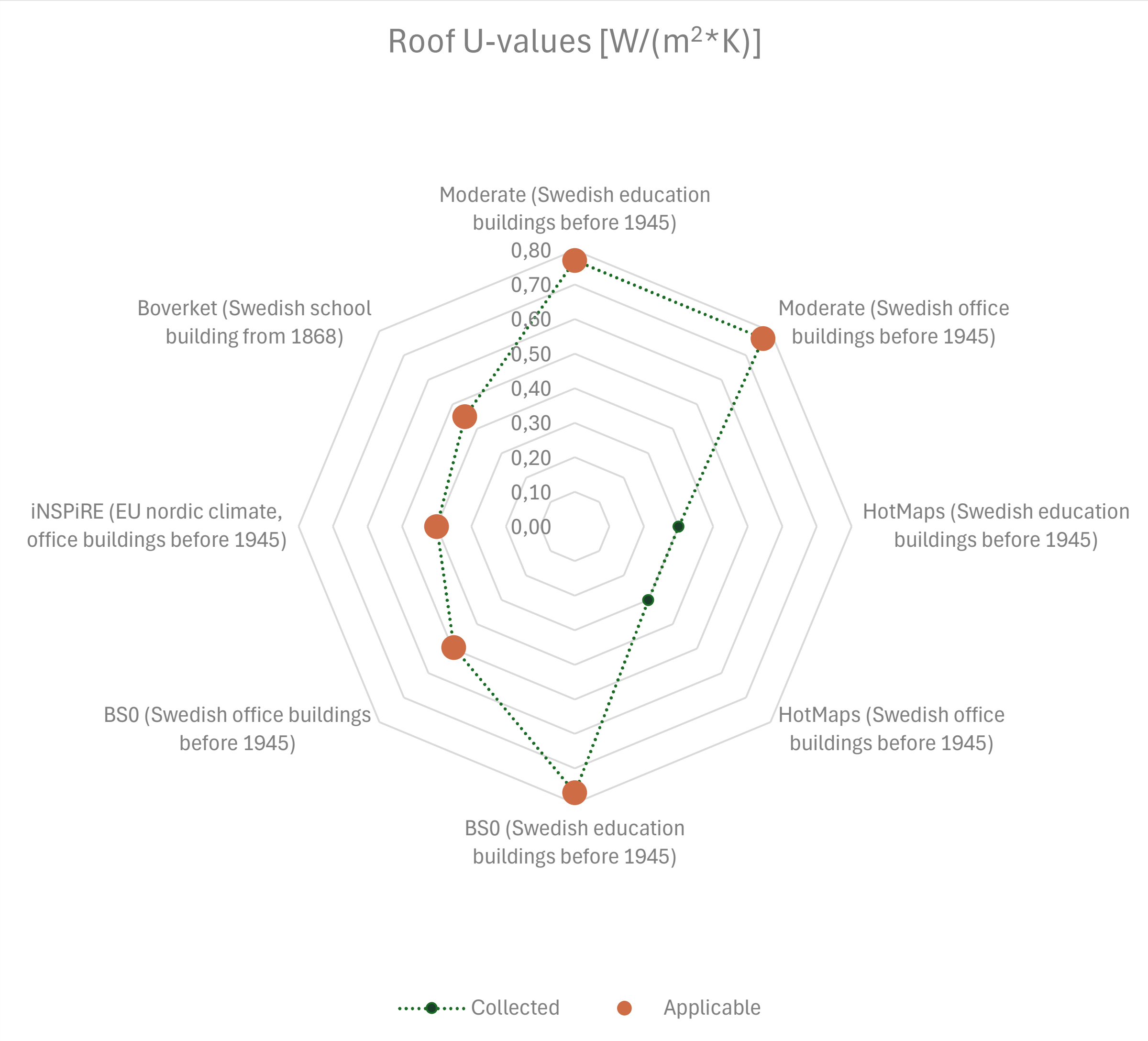


Figure 41. U-values identified for roofs of buildings with similar features to the typology "Monumentalbyggnad".

Floor

Figure 42 provides an overview of the data collected to define a U-value range for the floor of this typology. The U-values identified from Hotmaps for school and offices realized before 1945 have been excluded from the ranges because they represent the typical performance of retrofitted elements. The range identified for the floor of this typology is **0,40-0,50 W/(m²*K).**

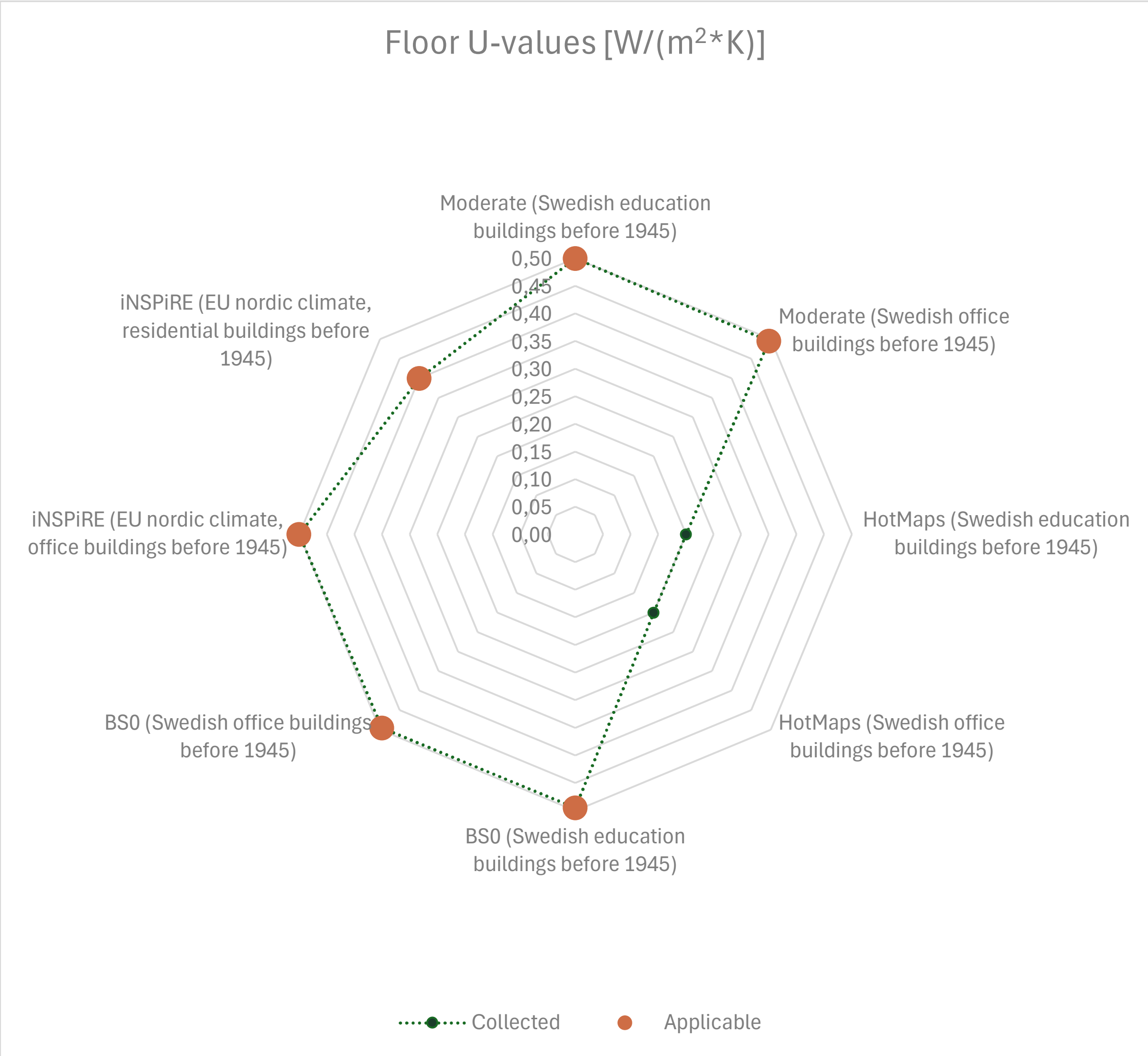


Figure 42. U-values identified for floors of buildings with similar features to the typology "Monumentalbyggnad".

Windows

Figure 43 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of coupled wooden frames with single glazing. The U-value range for the original typological element corresponds to **2,30- 3,20 W/(m²*K).**

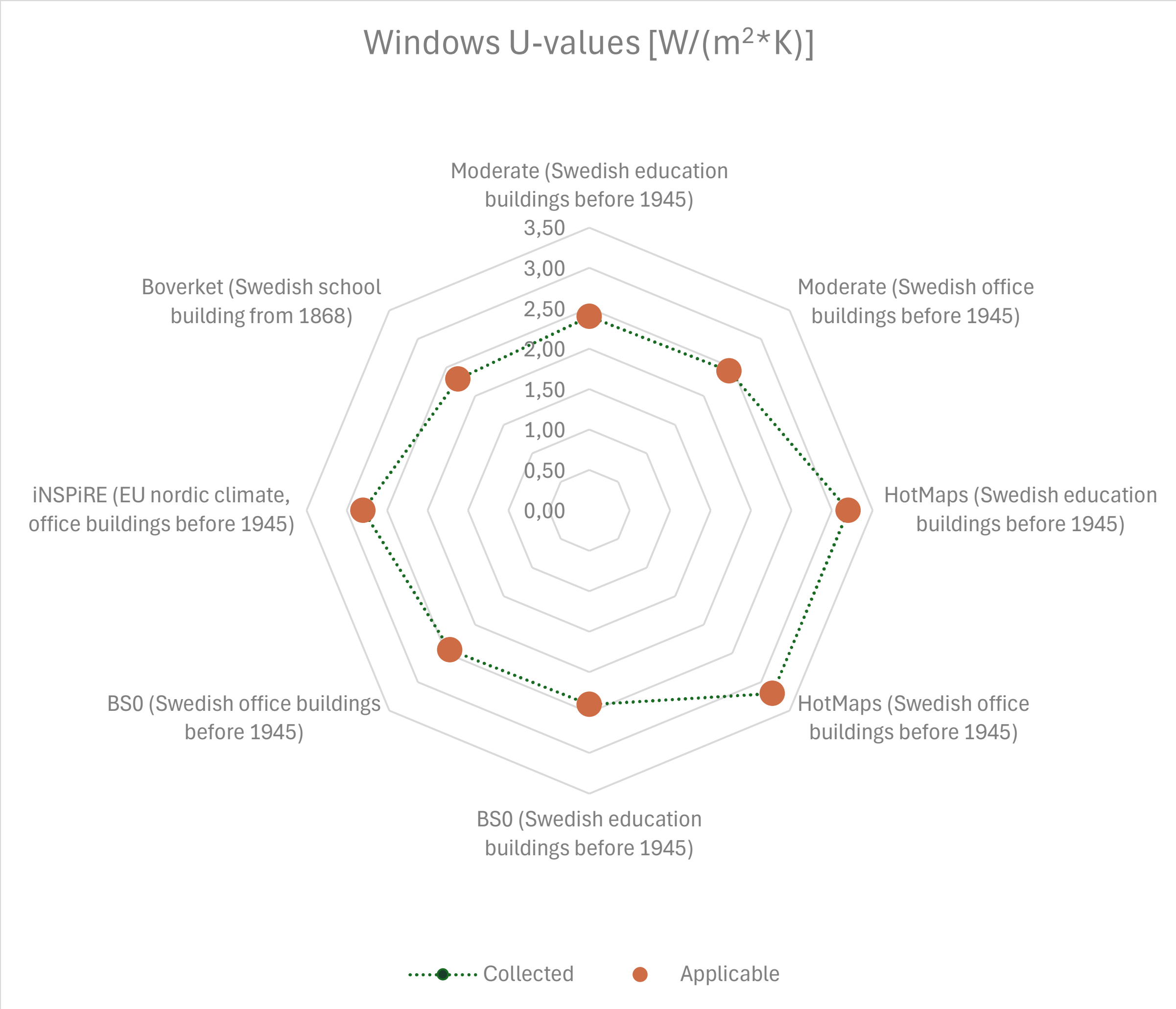


Figure 43. U-values identified for windows of buildings with similar features to the typology "Monumentalbyggnad".

Energy demand and consumption for heating and cooling

Figure 44 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **120-226 kWh/m² year**
- Cooling: **23-55 kWh/m² year**
- Heating and cooling: **143-281 kWh/m² year**

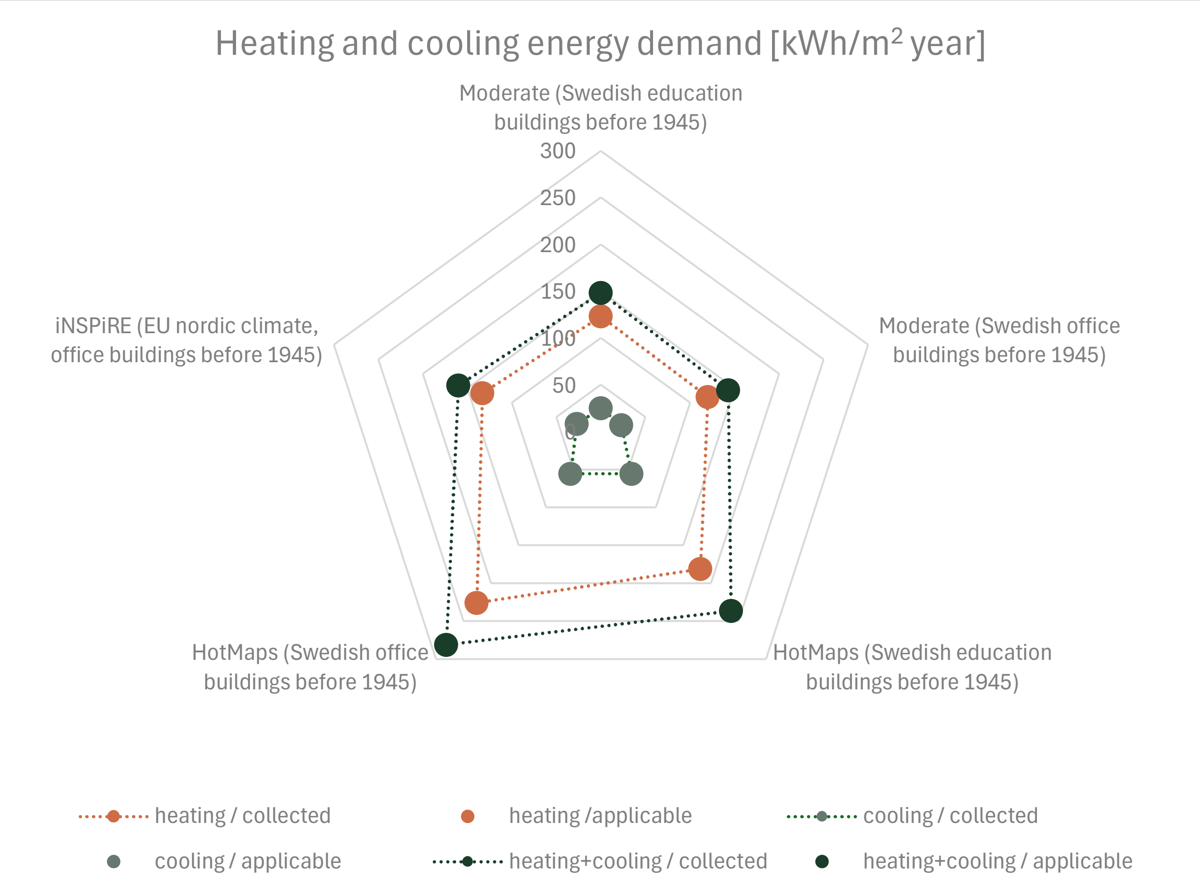


Figure 44. Energy demand data for heating and cooling identified for buildings with similar features to the typology "Monumentalbyggnad".

Some of the data sources used to collect information about heating demand also provided quantification of the energy consumption for heating and cooling. Further data about energy consumption have been retrieved from literature (Boverket, 2007), from the demonstrator building (measured energy consumptions) and from EPCs of public buildings realized in the 19th century in Sweden (provided by RISE). All these additional consumption data included both heating and hot water production. For this reason, they have been considered after subtracting the value for hot water consumption for buildings of the service sector built before 1945 in Sweden (18 kWh/m^2 year) retrieved in the Moderate dataset (2022). (This value is close to the one of residential buildings because the service sector includes also healthcare buildings.) Data provided by RISE includes the consumptions of 723 buildings; therefore, to increase accuracy, only average, 30th and 70th percentile have been included in the heating consumption range. The ranges identified for energy consumption are the following (Figure 45):

- Heating: **98-228 kWh/m^2 year**
- Cooling: **10-23 kWh/m^2 year**
- Heating and cooling: **148-251 kWh/m^2 year**

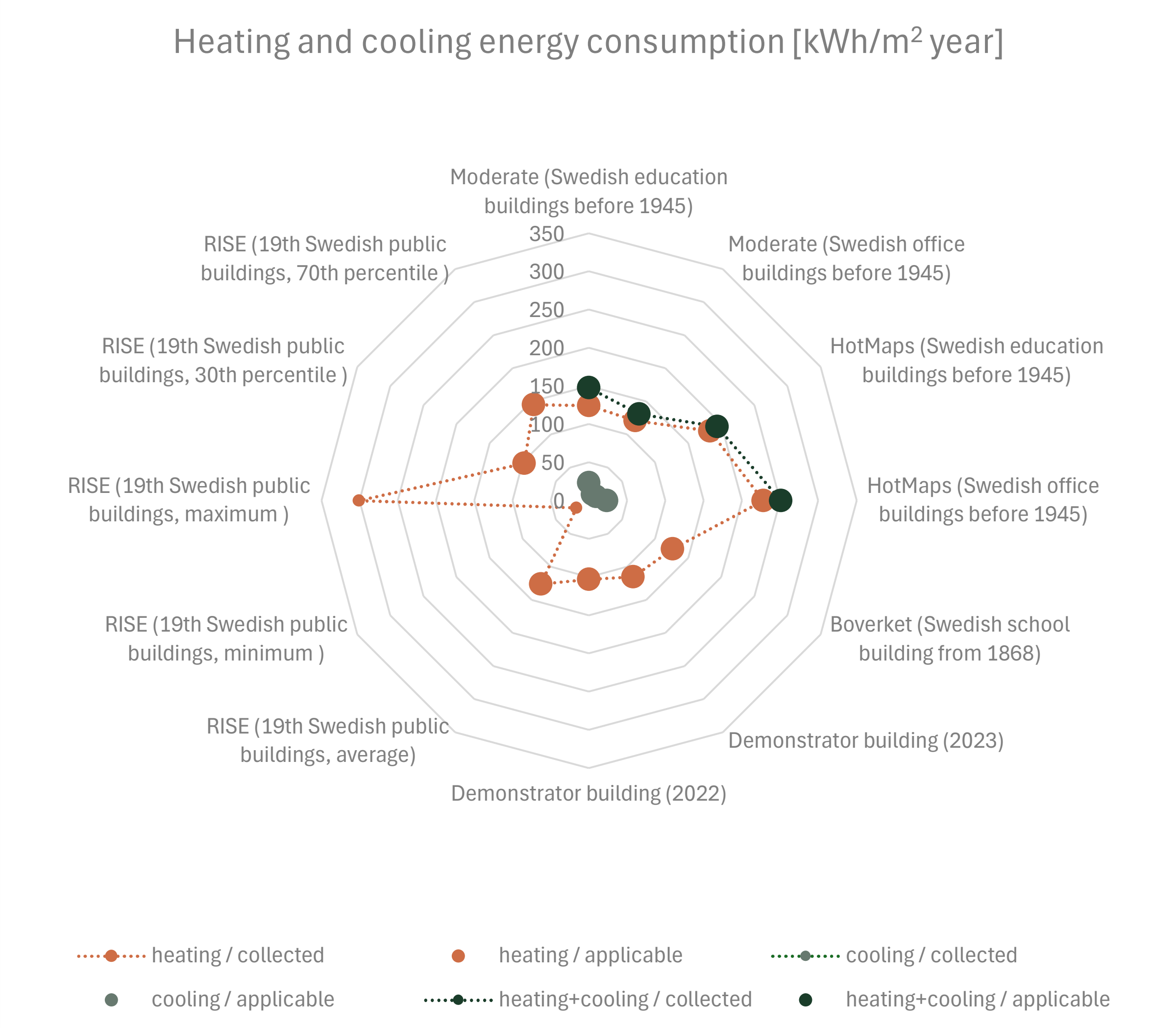


Figure 45. Energy consumption data for heating and cooling identified for buildings with similar features to the typology "Monumentalbyggnad".

3.8. Flerbostadshus funktionalism: Swedish functionalist multi-family housing block (1920-1945)

3.8.1. Contextualization of the typology

Origin and diffusion

The period between 1930 and 1950 marked a significant shift in Swedish architecture, driven by the principles of functionalism. This movement, introduced at the Stockholm Exhibition in 1930, was a reaction to the congested stone-built cities of the past and was heavily influenced by modernist ideals from France and Germany. The aim was to provide better living conditions for all, with a focus on practicality, efficiency, and social welfare (Figure 46).

Figure 46. Example of housing building from the 1930-40s in Sweden. Photo: Källberg, Sven https://digitaltmuseum.se

Today, a substantial portion of Sweden's housing stock is rooted in this functionalist era (Figure 47). Many of the apartment blocks built during the 1930s and 1940s still stand today, forming the backbone of several Swedish cities' residential neighborhoods. In Stockholm, Malmö, and Gothenburg, entire districts feature the characteristic straight-lined, functionalist buildings.

Figure 47. Example of housing building from the 1930-40s in Sweden. Photo: White Arkitekter

According to data extracted from the EU BSO (2024), multifamily houses and apartment blocks realized before 1945 correspond to **7,6%** of the buildings in Sweden. Furthermore, the dwellings corresponding to multifamily houses and apartment blocks realized before 1945 constitute **12,5%** of the dwellings recorded at national level.

Statistics Sweden provides a more detailed overview of the dwellings, revealing that **7,15%** of dwellings are located within multifamily housing realized between 1931 and 1940 (Figure 48).

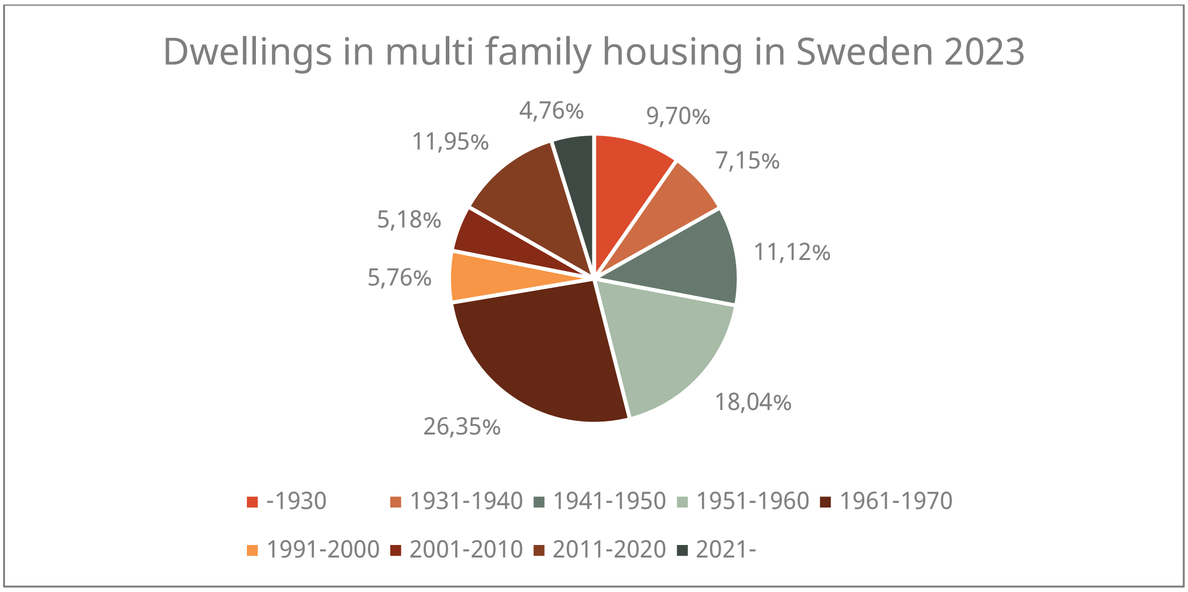


Figure 48. Dwellings in multifamily housing in Sweden in 2023. Source: Statistics Sweden.

Architectural features

Swedish architects sought to create buildings that served the needs of their inhabitants, rather than adhering to decorative or stylistic trends. Functionalism in urban planning saw the introduction of detached, multi-story residential buildings arranged in straight, parallel lines. These structures were designed to be harmonious with their natural environment, with existing landscapes and vegetation carefully preserved. This approach was applied across both residential and civic architecture, influencing not only housing estates but also public buildings like schools and hospitals.

During this era, residential architecture was dominated by three main types of buildings: the ‘thick house,’ the ‘narrow house,’ and the ‘point house.’ Each type was designed with efficiency and modesty in mind, optimizing space within the constraints of the time. Despite their compact sizes, these apartments were carefully planned to accommodate modern amenities, including preparation kitchens, bathrooms, and private dining areas. A strong emphasis was placed on accessibility to natural light, resulting in features like corner windows, made possible by advancements in glass manufacturing (Björk, 2000).

These buildings are built of reinforced concrete floor slabs and brick walls; thermally insulating layers are present in both horizontal and vertical elements of the envelope. The roof is pitched and built of timber structure; single-curved roof tiles are used as finishing layer for the roof (Björk, 1983).

3.8.2. Defining features of the typology

Table 17. Defining features of Swedish typology "Flerbostadshus funktionalism".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1920-1945*
	2	Climate	*Dfb Köppen-Geiger climate class*
	3	Original use	*Residential*
	4	Context	*Suburban*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	*Large (>300 m²)*
	7	Floor surface area (range)	*Large (>1000 m²)*
	8	Situation	*Detached (stand-alone building)*
Architectural characteristics	9	Architectural Style	*Functionalism*
	10	Envelope construction	• *Brick walls (25cm-thick) with or without a wood fibres layer (5 cm-thick), lime-cement plaster* • *Pitched roof, timber structure, single-curved roof tiles.* • *Reinforced concrete slab with glass wool insulation* • *Coupled windows, wooden frame, single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *3 to 4 floors of dwellings* • *Sufficient daylight for each apartment* • *One main staircase per building*
Heritage attributes	13	Heritage attributes to be preserved	• *Roof shape* • *Overall proportions*

3.8.3. Variable features of the typology

Table 18. Variable features of Swedish typology "Flerbostadshus funktionalism".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	*Back yard*
	16	Buffer spaces	• *Attic* • *Basement*
Heritage values	17	Typical level of protection	*Low (Local interest, partial protection)*
	18	Conservation area	*No*
	19	Authenticity (1:max-5:min)	*3*
	20	Integrity (1:max-5:min)	*3*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Technical* • *Architectural* • *Urban Planning*

3.8.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 49 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of solid bricks, eventually equipped with wood fibre insulation layers. The presence or not of this insulation layer has significant impact on the final U-value. Thus, and based on the data applicable to this construction, the U-value range generated for the walls of this typology is **0,58-2,23 W/(m²*K).**

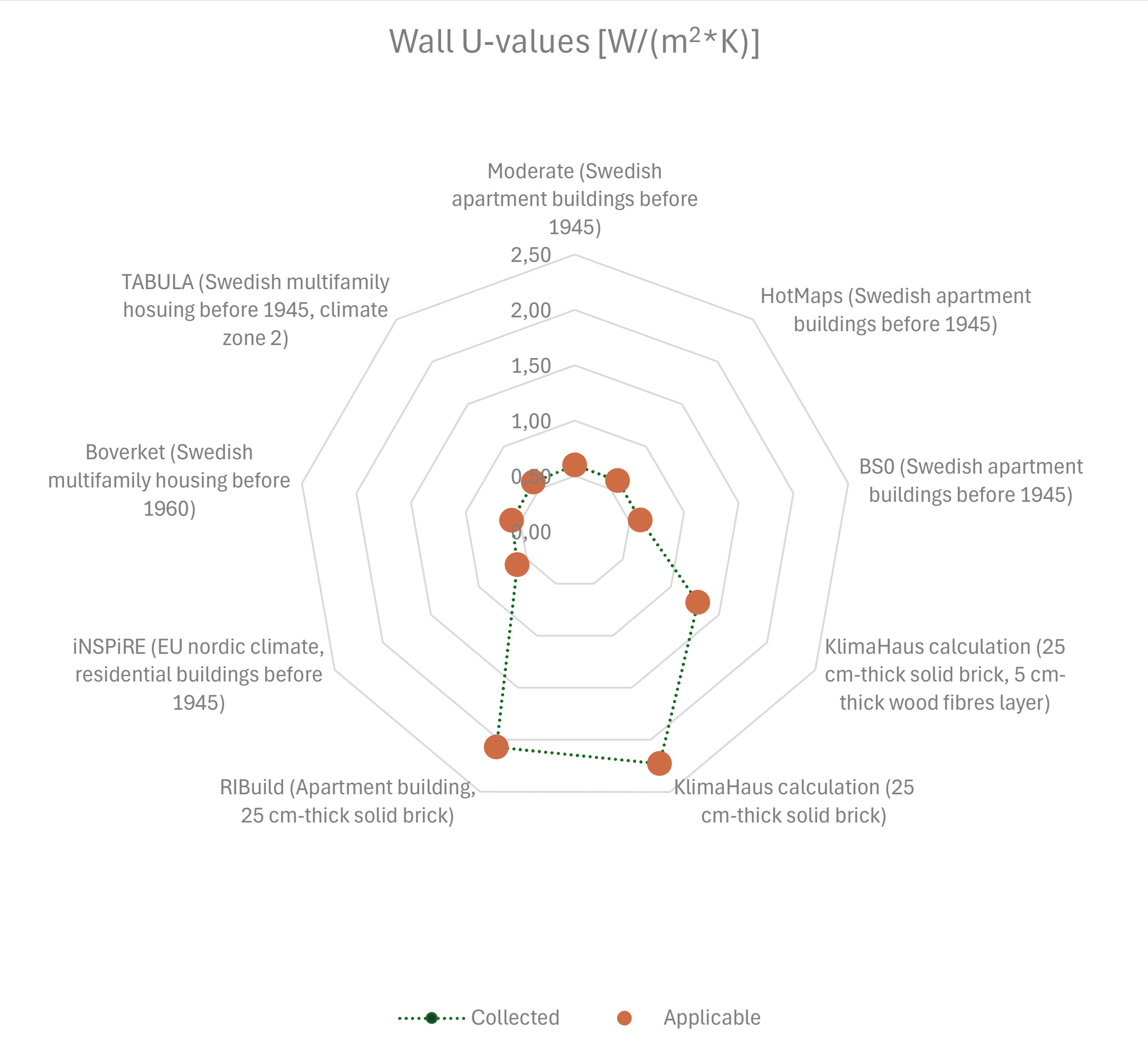


Figure 49. U-values identified for walls of buildings with similar features to the typology "Flerbostadshus funktionalism".

Roof

Figure 50 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value range generated for the roof of this typology is **0,36-0,50 W/(m²*K).**

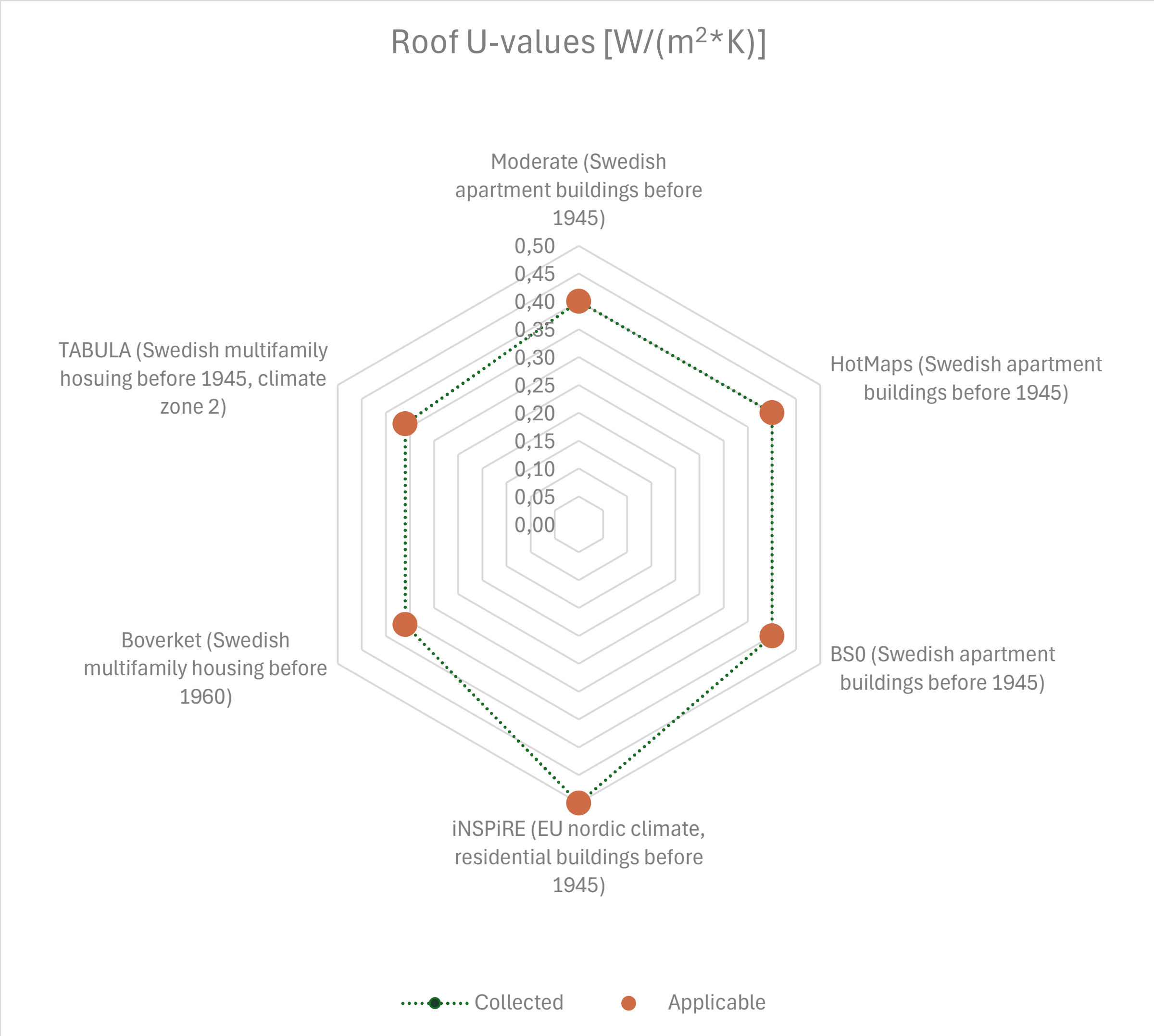


Figure 50. U-values identified for roofs of buildings with similar features to the typology "Flerbostadshus funktionalism".

Floor

Figure 51 provides an overview of the data collected to define a U-value range for the floor of this typology. These floors are usually built of concrete slab and equipped with glass wool insulation. The range identified for the floor of this typology is **0,30-0,40 W/(m²*K).**

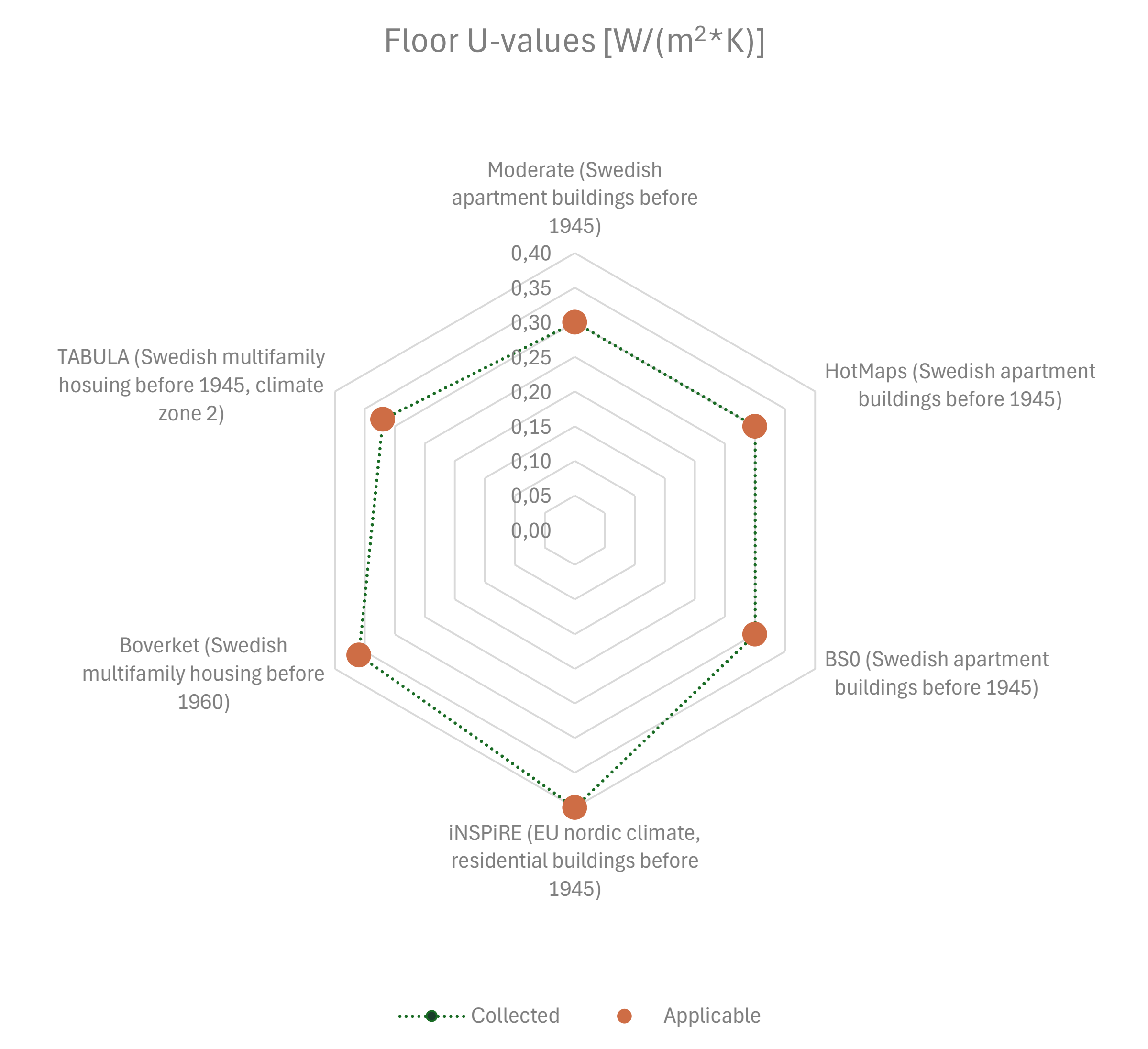


Figure 51. U-values identified for floors of buildings with similar features to the typology "Flerbostadshus funktionalism".

Windows

Figure 52 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of coupled wooden frames with single glazing. The U-value range for the original typological element corresponds to **2,22-3,20 W/(m²*K).**

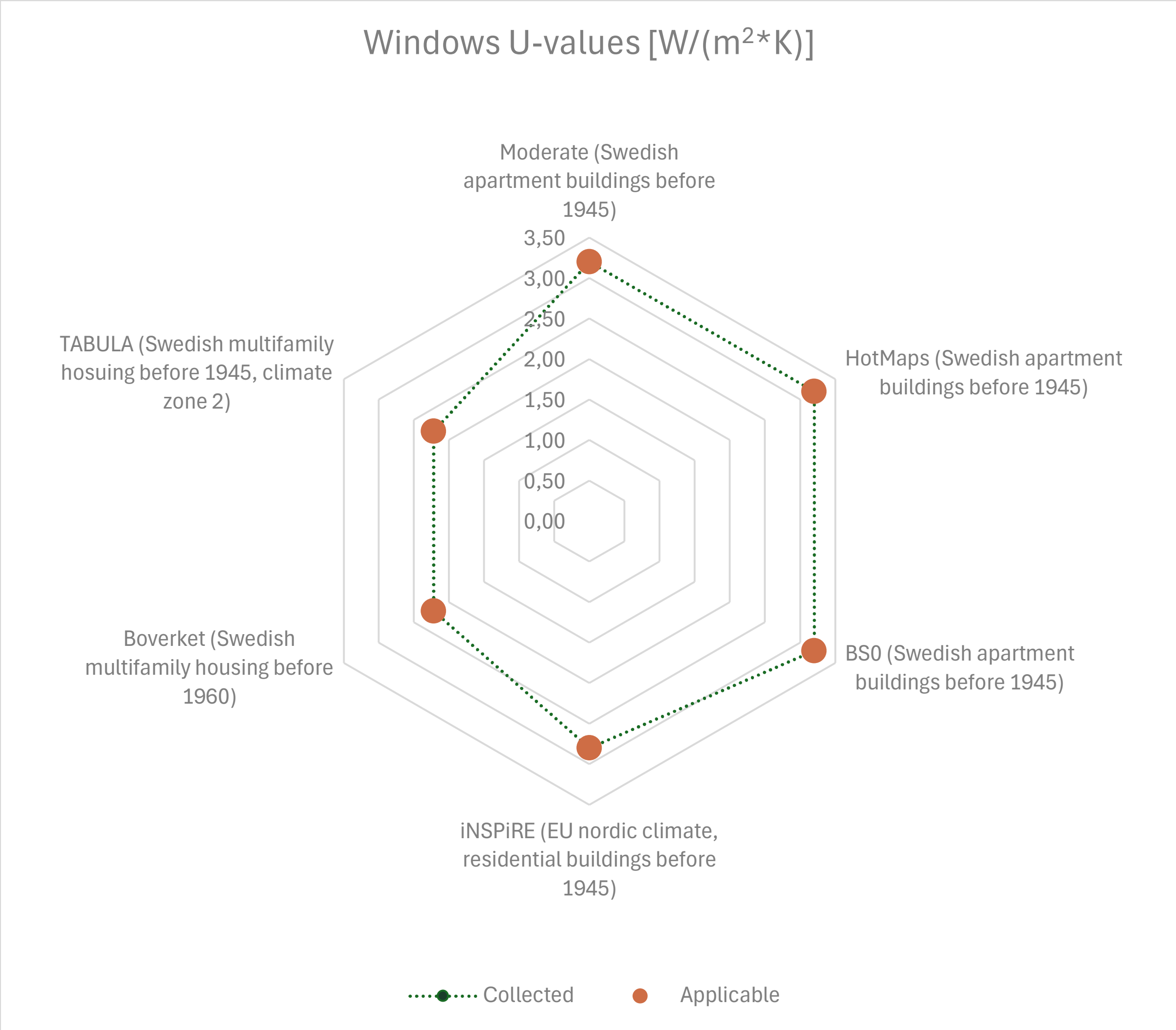


Figure 52. U-values identified for windows of buildings with similar features to the typology "Flerbostadshus funktionalism".

Energy demand and consumption for heating and cooling

Figure 53 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **79-183 kWh/m² year**
- Cooling: **14-27 kWh/m² year**
- Heating and cooling: **160-196 kWh/m² year**

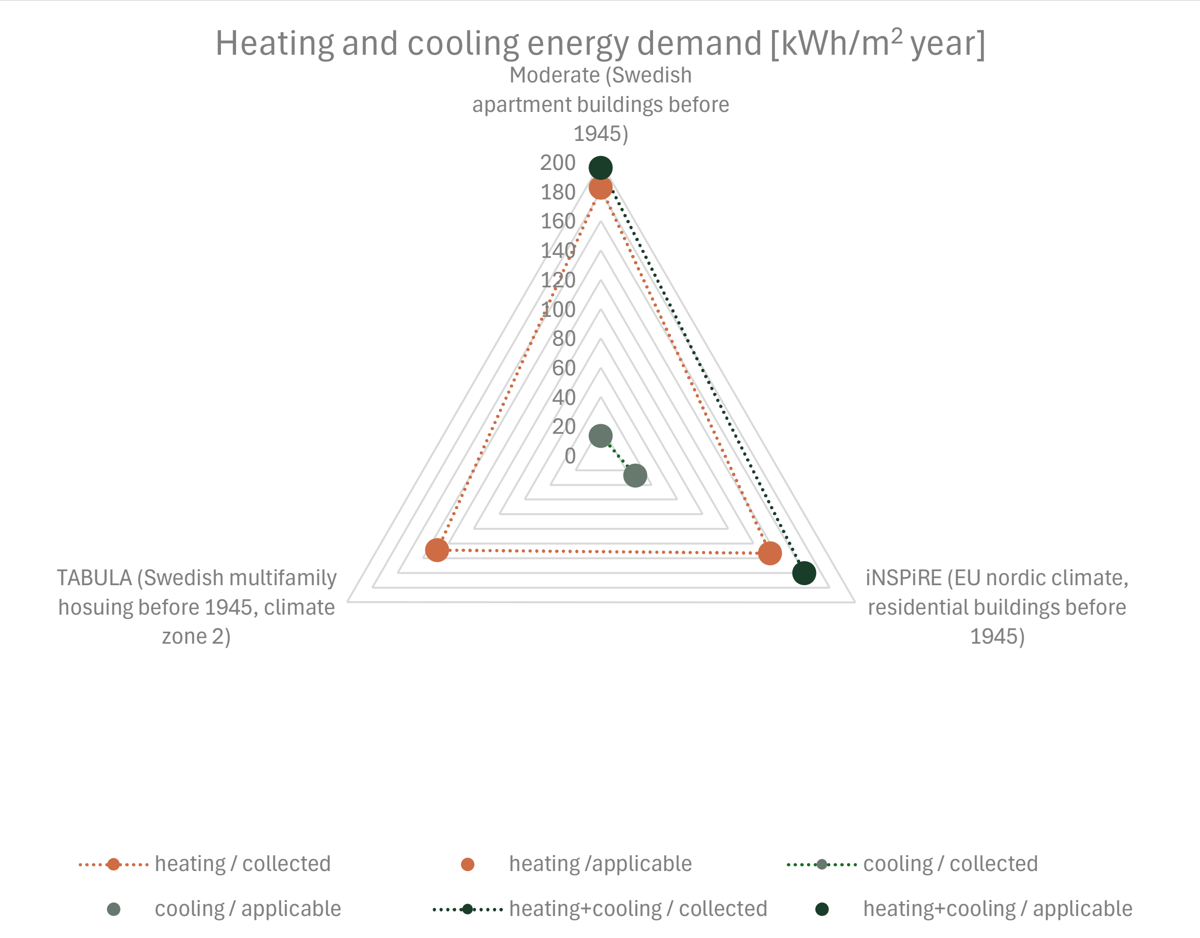


Figure 53. Energy demand data for heating and cooling identified for buildings with similar features to the typology "Flerbostadshus funktionalism".

Some of the data sources used to collect information about heating demand also provided quantification of the energy consumption for heating and cooling. (Figure 54). Data retrieved from literature (Dählstrom, 2024) and provided by RISE about the energy consumption for heating and hot water use (extracted from the EPCs of housing buildings from 1930s and 1940s) was considered after subtracting the average value (23 kWh/m^2 year) for hot water consumption for apartments block built before 1945 in Sweden (Moderate, 2022). Data provided by RISE includes the consumptions of 2971 buildings; to increase accuracy, only average, 30th and 70th percentile have been included in the heating consumption range. The ranges identified for energy consumption for heating is **77-231 kWh/m^2 year**. Data about energy consumption for cooling has been only retrieved in the Moderate dataset (2022) and corresponds to **4 kWh/m2 year.**

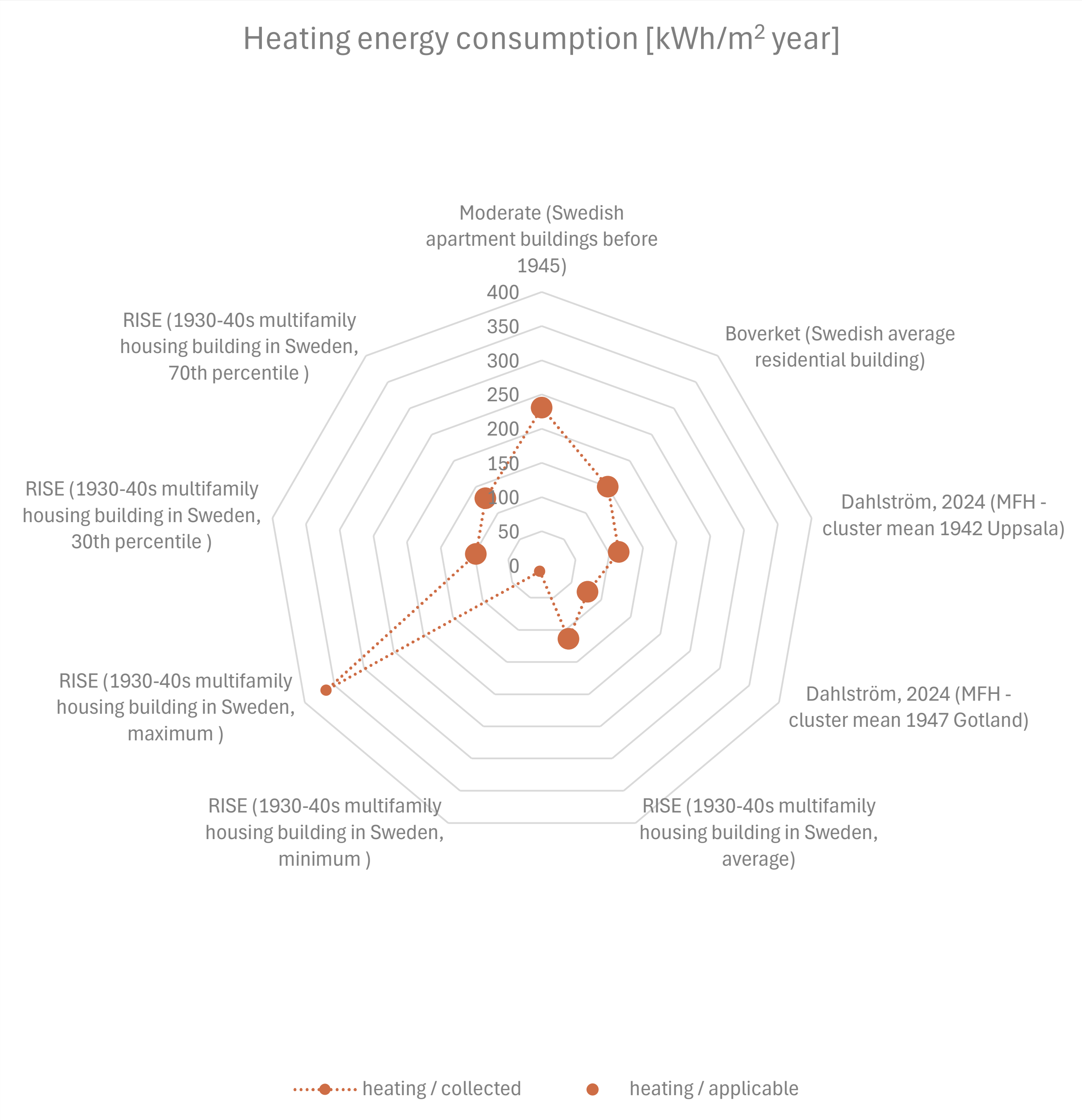


Figure 54. Energy consumption data for heating identified for buildings with similar features to the typology "Flerbostadshus funktionalism".

3.9. Georgian cottage: Scottish Georgian detached cottage (1750-1850)

3.9.1. Contextualization of the typology

Origin and diffusion

“Georgian cottage” is the typology defined for the 1st demonstrator building located in Scotland (Figure 55). This demonstrator building was designed to be part of a group of two lodges, or gatehouses, forming the entrance to the grounds of a late 18th century townhouse built for nobles and wealthy individuals. Lodges are suburban or rural detached buildings that can differ significantly in terms of form and architectural style/construction period. As such, a lodge typology would potentially not be relevant in terms of replicability. Therefore, it was decided to assimilate the lodge into the detached cottage category based on similarities (detached building, traditional material, construction techniques, architectural style) whilst bearing in mind the differences (plan/layout of the building and roof shape).

Cottages were originally designed as modest single-family houses built on the estate of a wealthy landowner. They had a small piece of land that was cultivated by the tenants to provide subsistence. As such, Georgian cottages could be found in most rural areas, and even in urban areas in Scotland. For instance, Fife features several well-preserved Georgian cottages, especially in the Culross area. Similarly, Dunbar, a coastal town, showcases examples of Georgian cottages along its streets. Luss, located on the banks of Loch Lomond, is another picturesque village that contains Georgian-style cottages. In Aberfeldy, the town hosts several Georgian cottages. Also, Stirling is home to numerous Georgian cottages, particularly in its Old Town. Moreover, in the islands, particularly in Orkney features several well-preserved examples of Georgian cottages across its towns, e.g. Kirkwall, South Ronaldsay, and Westray.

Figure 55. First demonstrator building in Scotland, Georgian Lodge in Edinburgh. Source: EWHT.

Cottages represent the typical single-family house for farm labourers or small farmers during the Georgian period (Figure 57). According to data extracted from the dataset of the Hotmaps project (2020), single family houses (detached and terraced) realized before 1945 correspond to **5,34%** of the buildings in the UK. Furthermore, the dwellings corresponding to single-family houses realized before 1945 constitute **7,12%** of the dwellings recorded in the UK.

Figure 56. Duddingston Village, Edinburgh, traditional Cottage with lime render finish. The cottage is believed to be detached before being surrounded by other buildings. Source: EWHT

Architectural features

Georgian cottage architecture reflects the influence of the Georgian period and, sometimes, exhibits a symmetrical façade with evenly spaced windows and doors, emphasizing symmetry and proportion. However, vernacular Georgian cottage architecture is more asymmetric and less formal (Figure 57). Local stone, ashlar or rubble, is commonly used in their construction, often finished with a lime render or limewash that gives the cottages a distinctive appearance and protect them from climate elements. Cottages are usually one up to two-storey high. Georgian cottages also feature traditional multi-pane sash and case windows. However, windows in cottages are usually smaller than those in Georgian tenements and terraced houses. Additionally, gabled roofs are prevalent and usually finished with slates. These elements are durable and weather-resistant, making them suitable for the damp climate of Scotland. The roof channels the rainwater through cast iron gutters connected to cast iron downpipes.

Figure 57. Duddingston Village, Edinburgh, traditional Cottage with lime render finish. The cottage is believed to be detached before being surrounded by another building. Source: EWHT

3.9.2. Defining features of the typology

Table 19. Defining features of Scottish typology "Georgian cottage".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1750-1850*
	2	Climate	*Cfc and Cfp Köppen-Geiger climate class*
	3	Original use	*Residential*
	4	Context	*Rural*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	*Small (<150 m^2)*
	7	Floor surface area (range)	*Small (<200 m^2)*
	8	Situation	*Detached (stand-alone building)*
Architectural characteristics	9	Architectural Style	*Georgian*
	10	Envelope construction	• *Rubble stone masonry (~60 cm-thick) and external lime render (alternatively ashlar or lime wash), internal lath and plaster* • *Pitched roof, wooden beams, Scottish slates* • *Ground floor made of flag stone* • *Sash windows, timber frame and single glazing*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Internal circulation* • *Direct lighting* • *Internal staircase*
Heritage attributes	13	Heritage attributes to be preserved	• *Façade* • *Original sash and case windows* • *Masonry screen wall* • *Roof design and materials* • *Internal heritage features (e.g., cornices fireplaces)*

3.9.3. Variable features of the typology

Table 20. Variable features of Scottish typology "Georgian cottage".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	• *Front yard* • *Backyard*
	16	Buffer spaces	• *Attic*
Heritage values	17	Typical level of protection	*Low (Regional or local interest, partial protection)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*3*
	20	Integrity (1:max-5:min)	*3*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Technical* • *Architectural* • *Historic* • *Urban Planning*

3.9.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 58 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of natural stone. For this reason, data extracted from Hotmaps and TABULA has been excluded as it refers to brickwork walls. Based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,30-2,32 W/(m²*K).**

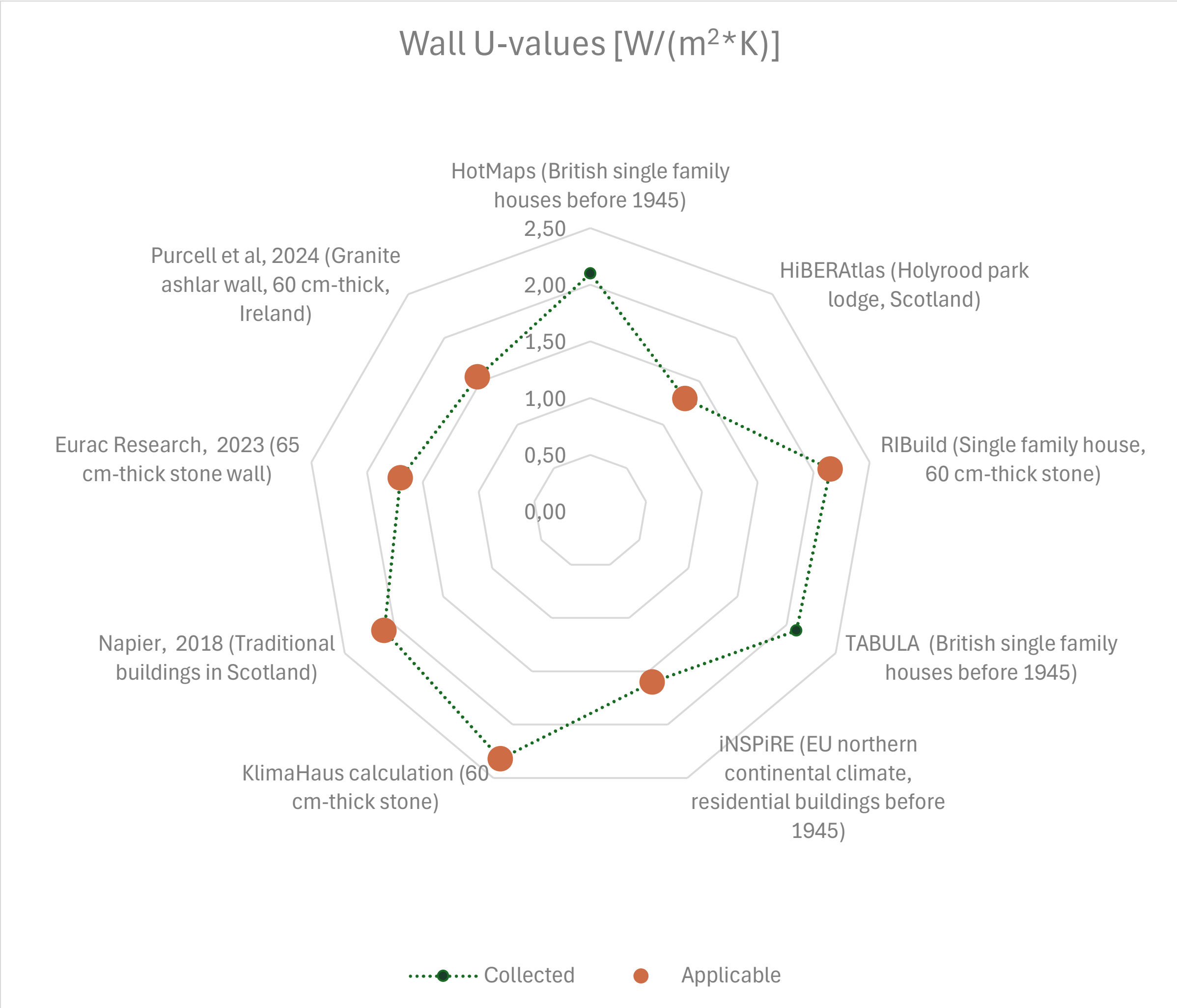


Figure 58. U-values identified for walls of buildings with similar features to the typology "Georgian cottage".

Roof

Figure 59 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value range generated for the roof of this typology is **1,00-2,30 W/(m²*K).**

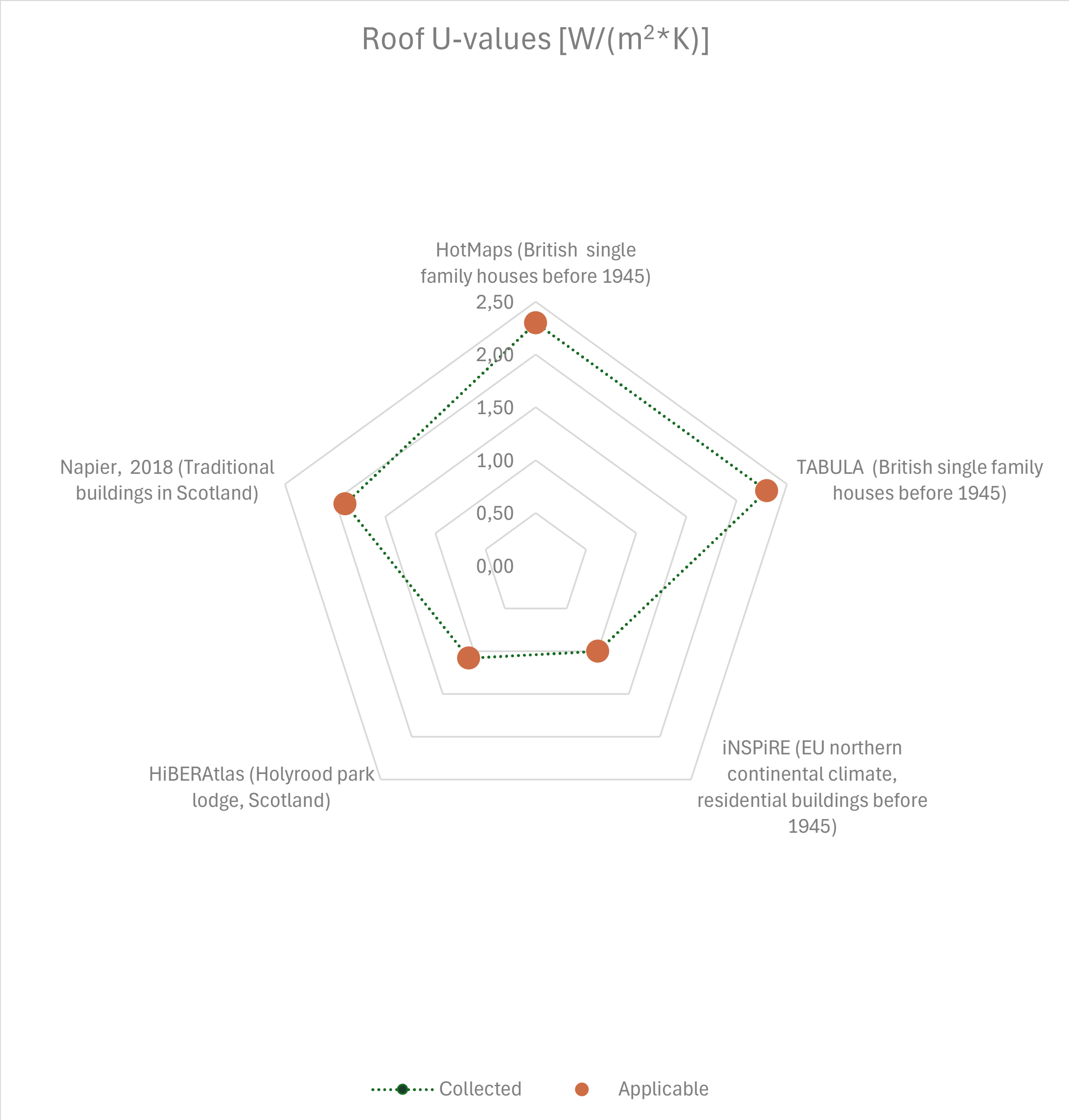


Figure 59. U-values identified for roofs of buildings with similar features to the typology "Georgian cottage".

Floor

Figure 60 provides an overview of the data collected to define a U-value range for the floor of this typology. These floors are usually built of timber structure. The values extracted from Hotmaps and TABULA have been excluded as they are too low to represent the original construction type. The range identified for the floor of this typology is **1,60-3,90 W/(m²*K).**

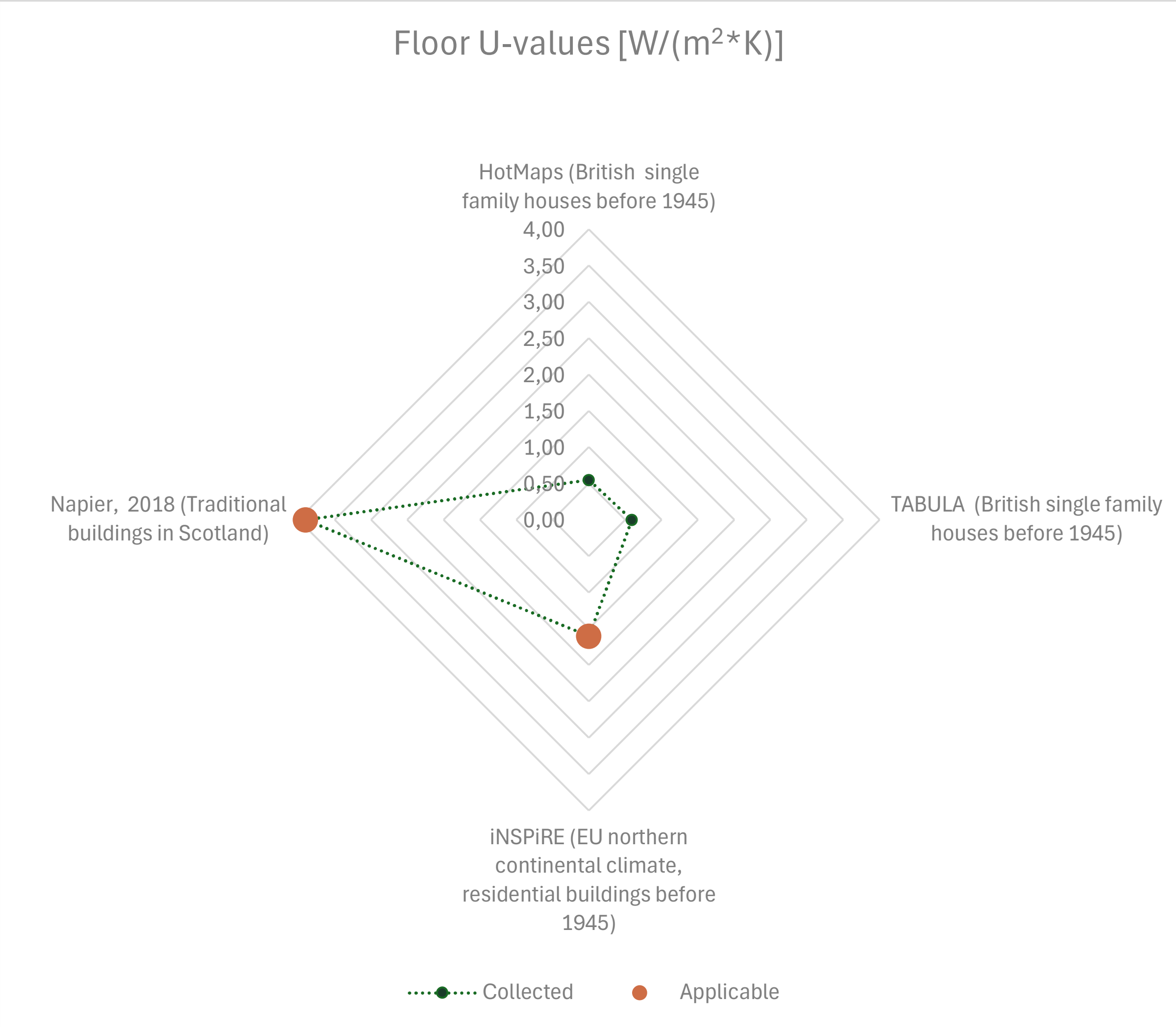


Figure 60. U-values identified for floors of buildings with similar features to the typology "Georgian cottage".

Windows

Figure 61 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. The U-value range for the original typological element corresponds to **3,60-5,40 W/(m²*K).**

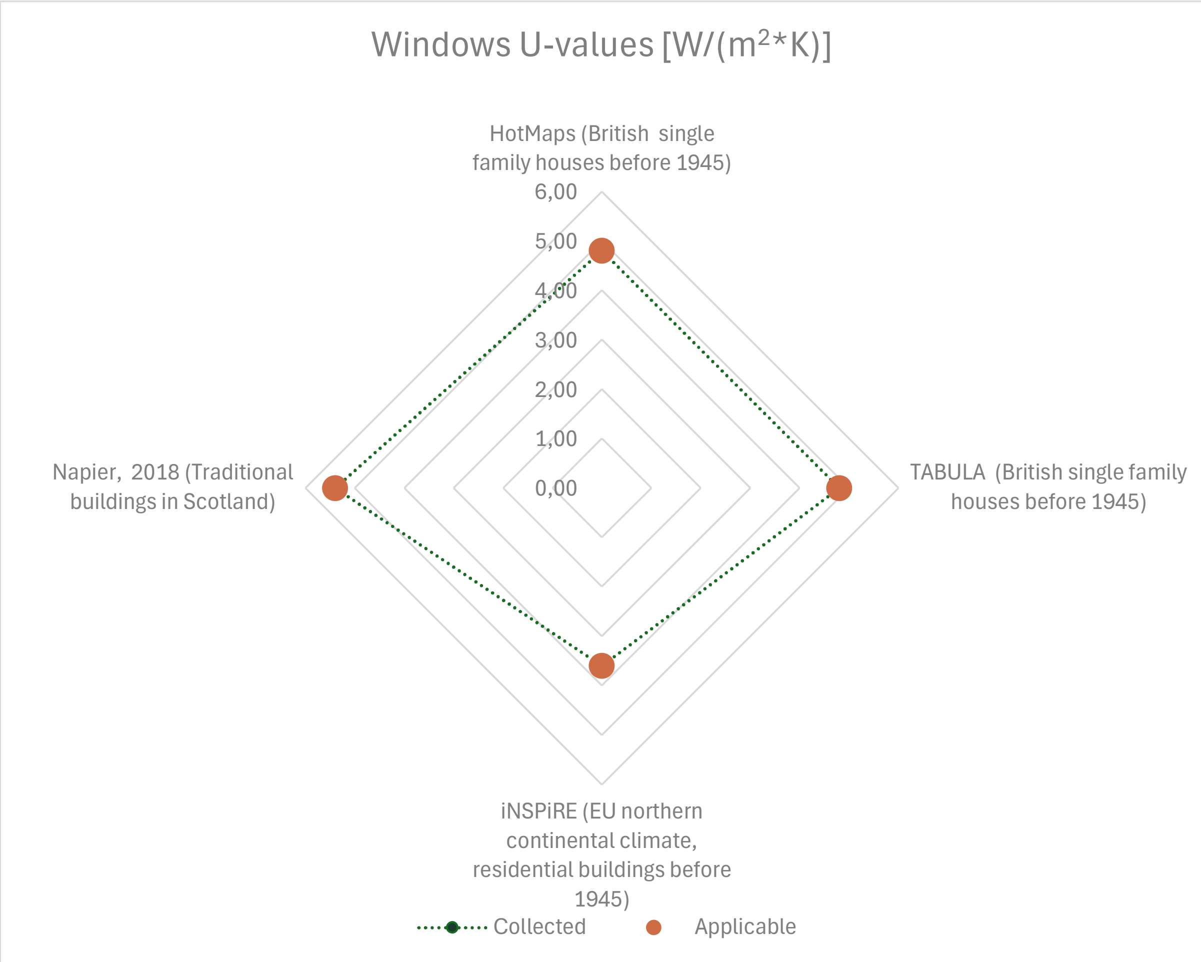


Figure 61. U-values identified for windows of buildings with similar features to the typology "Georgian cottage".

Energy demand and consumption for heating and cooling

Figure 62 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **126-211 kWh/m² year**
- Cooling: **24-36 kWh/m² year**
- Heating and cooling: **162-234 kWh/m² year**

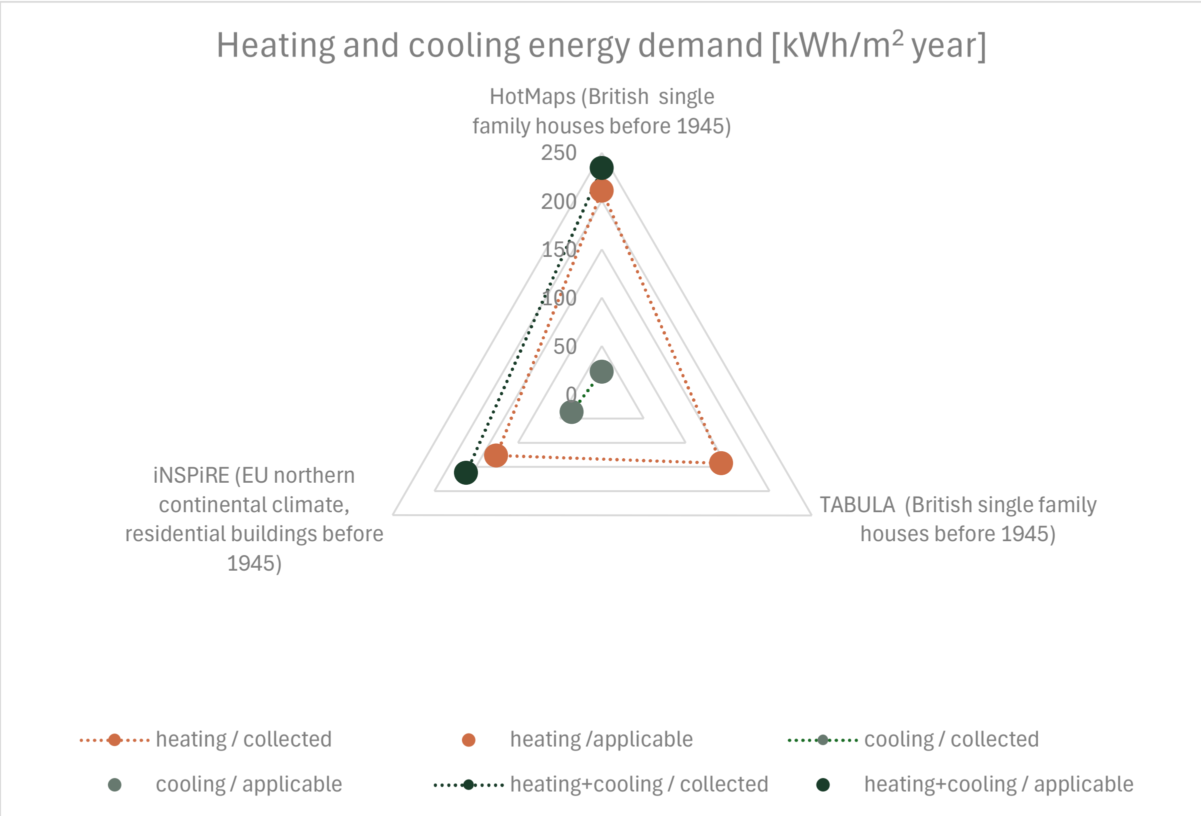


Figure 62. Energy demand data for heating and cooling identified for buildings with similar features to the typology "Georgian cottage".

Hotmaps (2020) also provided the following data about the energy consumptions of single-family houses realized in the UK before 1945:

- Heating: **268 kWh/m² year**
- Cooling: **4 kWh/m² year**
- Heating and cooling: **271 kWh/m² year**

3.10. Georgian tenement: Scottish Georgian terraced tenement building (1750-1850)

3.10.1. Contextualization of the typology

Origin and diffusion

“Georgian tenement” is the typology defined for the 2nd demonstrator building located in Scotland (Figure 63). Scottish tenement buildings, which became prominent from the 19th century, were designed to address urban housing shortages, especially during the Industrial Revolution. These multi-storey residential structures (Figure 64) were built to accommodate the growing population in Scottish cities like Edinburgh and Glasgow, reflecting a mix of Georgian (1730-1860) and Victorian (1860-1900) architectural influences.

Figure 63. Georgian Tenement building, Lauriston Place, Edinburgh’s Old Town. View of the south facade. Source: EWHT.

The cultural aspect of Scottish tenements is rich and multifaceted, reflecting the social history and communal life of urban Scotland. This communal living was essential, especially for working-class families, but also provided housing for people from different economic backgrounds.

Though most surviving tenements in Scotland are from the 19th century, however, the tenement type has precedent in the pre-Georgian era in Scotland (pre1750), especially in Edinburgh. Pre-Georgian tenements in Edinburgh's Old Town date back to the medieval period, primarily emerging between the 15th and 17th centuries. They resulted from the need to build upwards due to the combined effect of a growing population and lack of space within the town walls. These buildings reflect a unique architectural evolution that shaped the character of the Old Town, characterized by narrow, multi-storey structures designed to maximize space in a densely populated urban environment. Compared to the later Georgian and Victorian styles, early tenements had a more functional design with less ornamentation, and often housed both residential and commercial spaces. Ground floors frequently included shops, and workshops, whilst upper levels were designed for residential use, accommodating different social classes - generally, the wealthier families living in the lower floors and poorer ones in upper floors.

Figure 64. Georgian Tenement Building, Dundas Street, Edinburgh's New Town. Source: EWHT.

Traditional tenements in Scotland are primarily found in urban areas, particularly in cities that experienced significant population growth during the Industrial Revolution and the Victorian era. Here are some key locations:

- Edinburgh: The Old Town features some historic tenements, showcasing medieval architecture. The New Town, developed in the 18th century, also includes tenement-style buildings from the Georgian and Victorian period.
- Glasgow: Glasgow is renowned for its tenement buildings, especially in neighbourhoods like the West End and the South Side. Many were built in the late 19th and early 20th centuries, reflecting the city's industrial heritage.
- Other major cities: Dundee, Aberdeen, and Inverness, have a range of tenement buildings particularly in their centres and the older neighbourhoods.
- Smaller towns and cities throughout Scotland, particularly those that grew during the 19th century, also contain tenements, though they may not be as prevalent as in larger urban centres.

Overall, while tenements are most famously associated with Edinburgh and Glasgow, they are an integral part of the architectural landscape in various Scottish cities and towns, reflecting local history and community life.

According to data extracted from the dataset of the Hotmaps project (2020), multifamily houses and apartment blocks realized before 1945 correspond to **4,4%** of the buildings in the UK. Furthermore, the dwellings corresponding to multifamily houses and apartment blocks realized before 1945 constitute **5,9%** of the dwellings recorded in the UK.

Housing survey conducted at UK and Scottish level provided more quantitative data to assess the representativeness of tenement houses. According to the Scottish Housing Condition Survey (2017), the total number of the pre-1919 dwellings in Scotland is 473,000 of which 182,000 are flats. The Scottish Housing Condition Survey also shows that the number of the pre 1919 dwellings in Edinburgh is 80,000 of which 53,000 flats. The Scottish housing condition survey uses the term "flats". However, it is known that pre 1919 flats are called tenements, hence, the term "tenement" is used instead of "flat" in this study. According to the Scottish House Condition Survey 2017, the number of dwellings of all types in Scotland is 2,603,174. Hence, pre-1919 tenement dwellings ratio to all building types in Scotland is **6,99%.** Just Edinburgh's pre-1919 tenements houses correspond to 2,04% of total Scottish dwellings.

According to the Bre Trust report on the Housing Stock of The United Kingdom (2020), the total number of the pre-1919 dwellings in the UK is 5,871,000.

The above statistics suggests the following analysis:

- UK scale:
  - Scotland's pre-1919 building stock consists 8.06% of the of the overall UK pre-1919 building stock
  - Scotland's pre-1919 tenements stock consists 3.10% of the overall UK pre-1919 building stock
- Scotland scale:
  - Edinburgh's pre-1919 building stock consists 16.91% of Scotland's pre-1919 building stock.

Edinburgh's pre-1919 tenements stock consists 11.21% of Scotland's pre-1919 building stock.

Architectural features

Scottish tenements are distinctive residential buildings that feature several key architectural characteristics. Here are the main features:

- Arrangement and density: Tenements are multi-storey buildings typically ranging from three to six stories. They are designed to maximize living space in urban areas where land is scarce, or land cost is high. Tenements often occupy narrow plots, with multiple units stacked vertically, contributing to high population density. In the Georgian and Victorian period, tenements were built in row configuration called terraces, typically arranged in long, continuous rows, with each unit having its own entrance and including shared staircase. This layout maximizes the use of urban space.
- Shared entrance and staircase: Tenements usually have a shared entrance leading to a central staircase that provides access to individual flats on different levels. Ground floor and basement flats would have their own door and a direct access from the street – from a staircase and via a courtyard for the latter. The main front doors and the fanlights above them are recurring

features; their design tends to be similar for all the buildings of a given street and vary slightly from one street to another.

- Walls: built with local stone, these buildings have thick walls, which provide insulation and structural support. The front façade is built of ashlar stone whilst the rear is made of rubble masonry. They are often lined by lath and plaster system, separated from the masonry wall by a narrow cavity that allows air flow and remove any damp in the walls.

- Internal spaces: depending on the period, architectural style and the expected quality standard, rooms in tenements built post-1750 generally feature high ceilings, often exceeding 3 meters, contributing to a feeling of spaciousness. Also, many tenements display decorative features like cornices and plaster mouldings that reflect the architectural style of each era.

- Windows and lighting: tenements typically have large, vertically proportioned windows to allow natural light – although this can vary depending on the architectural style and period of the building. The main type of these windows is the sash and case window, which consists of two frames sliding vertically, and usually divided into smaller panes that differ in number depends on the architectural style. Some tenements feature projecting bay windows that were more common during the Victorian era.

- Roof design: the roofs are typically pitched, often with slate tiles, and sometimes feature dormer windows. There are various in the design of the roof depending one the period and architectural style. Tenements from the Georgian period could have a single pitched roof, or double pitched roof or what is known as an M-shape roof, whilst Victorian period have mansard roofs in different variations.

- Geographical variations: while the basic tenement form is consistent, there are regional variations influenced by local materials and architectural styles, such as the more ornate features in Glasgow compared to the simpler forms in Edinburgh.

These architectural characteristics collectively define Scottish tenements, making them not only functional living spaces but also significant cultural and historic landmarks in Scotland's urban landscape.

3.10.2. Defining features of the typology

Table 21. Defining features of Scottish typology "Georgian tenement".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1750-1850*
	2	Climate	*Cfc and Cfp Köppen-Geiger climate class*
	3	Original use	*Residential*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	• *Medium (150<>300 m2)* • *Large (>300 m^2)*
	7	Floor surface area (range)	• *Medium (200<>1000 m^2)* • *Large (>1000 m^2)*
	8	Situation	*Infill (adjoining buildings on two or more sides)*
Architectural characteristics	9	Architectural Style	*Georgian (neoclassical)*
	10	Envelope construction	• *Droved ashlar with polished cills (~60cm-thick), some polished ashlar at ground floor, rubble (some coursed) to rear* • *Pitched or M shaped (double pitched) roof, wooden beams, Scottish slates* • *Suspended timber floors* • *Sash windows, timber frame, single glazing*
	11	WWR (range)	• *Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *common stair well that provide access to upper stories (basement and ground floor flats are usually accessed directly from the street level)* • *Natural light from two different sides*
Heritage attributes	13	Heritage attributes to be preserved	• *Façade and materials* • *Original sash and case windows* • *Front doors and fanlight* • *External railings and platts at the front* • *Roof design and materials* • *Internal heritage features (cornices, chimneys, staircase, etc.)* • *Internal layout/distribution and function of the rooms for the best-preserved examples*

3.10.3. Variable features of the typology

Table 22. Variable features of Scottish typology “Georgian tenement”.

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	• *Front yard* • *Backyard*
	16	Buffer spaces	• *Attic* • *Basement*
Heritage values	17	Typical level of protection	*Medium (National interest)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*2*
	20	Integrity (1:max-5:min)	*2*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Technical* • *Architectural* • *Historic* • *Urban Planning*

3.10.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 65 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of natural stone. For this reason, data extracted from Hotmaps and TABULA has been excluded as it refers to brickwork walls. Based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,30-2,32 W/(m²*K).**

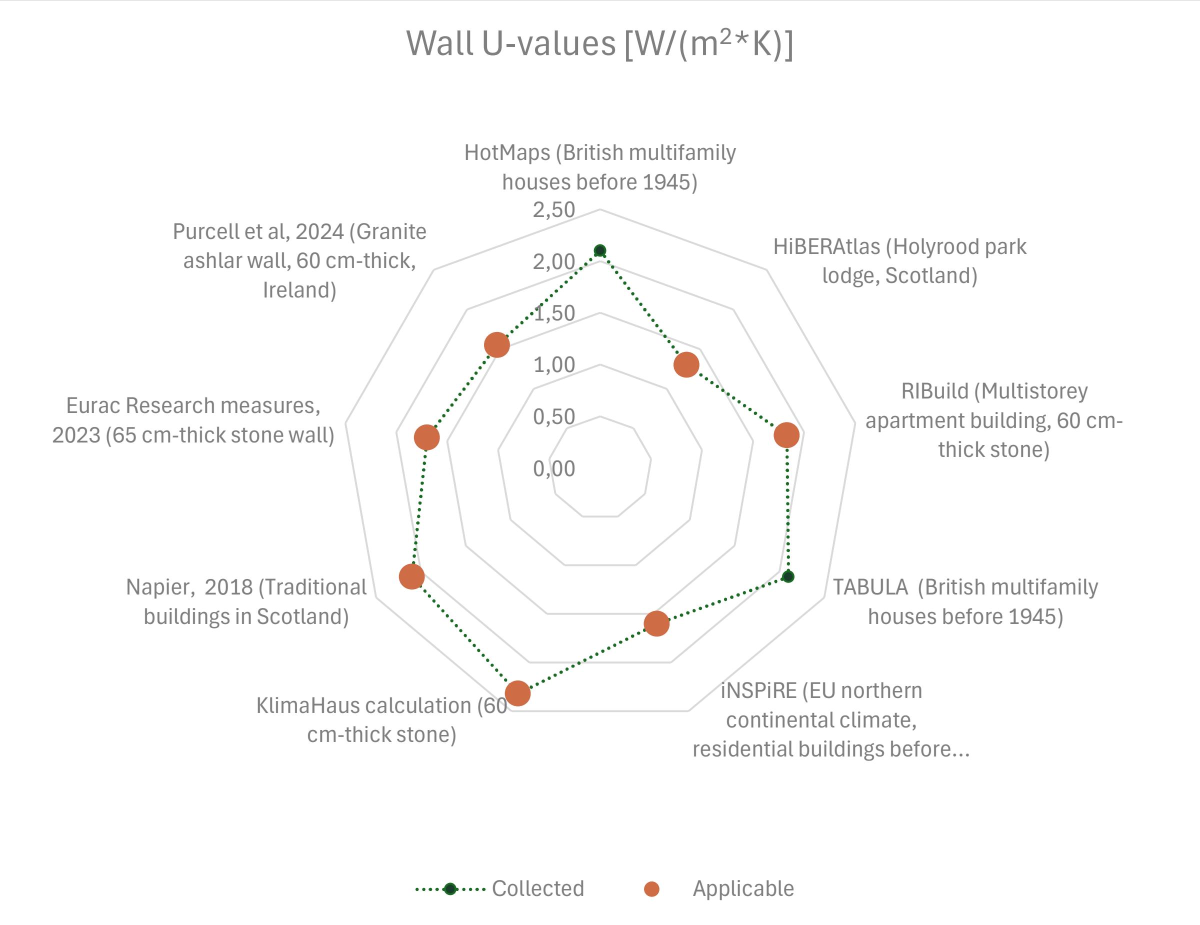


Figure 65. U-values identified for walls of buildings with similar features to the typology "Georgian tenement".

Roof

Figure 66 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value range generated for the roof of this typology is **1,00-2,30 W/(m²*K).**

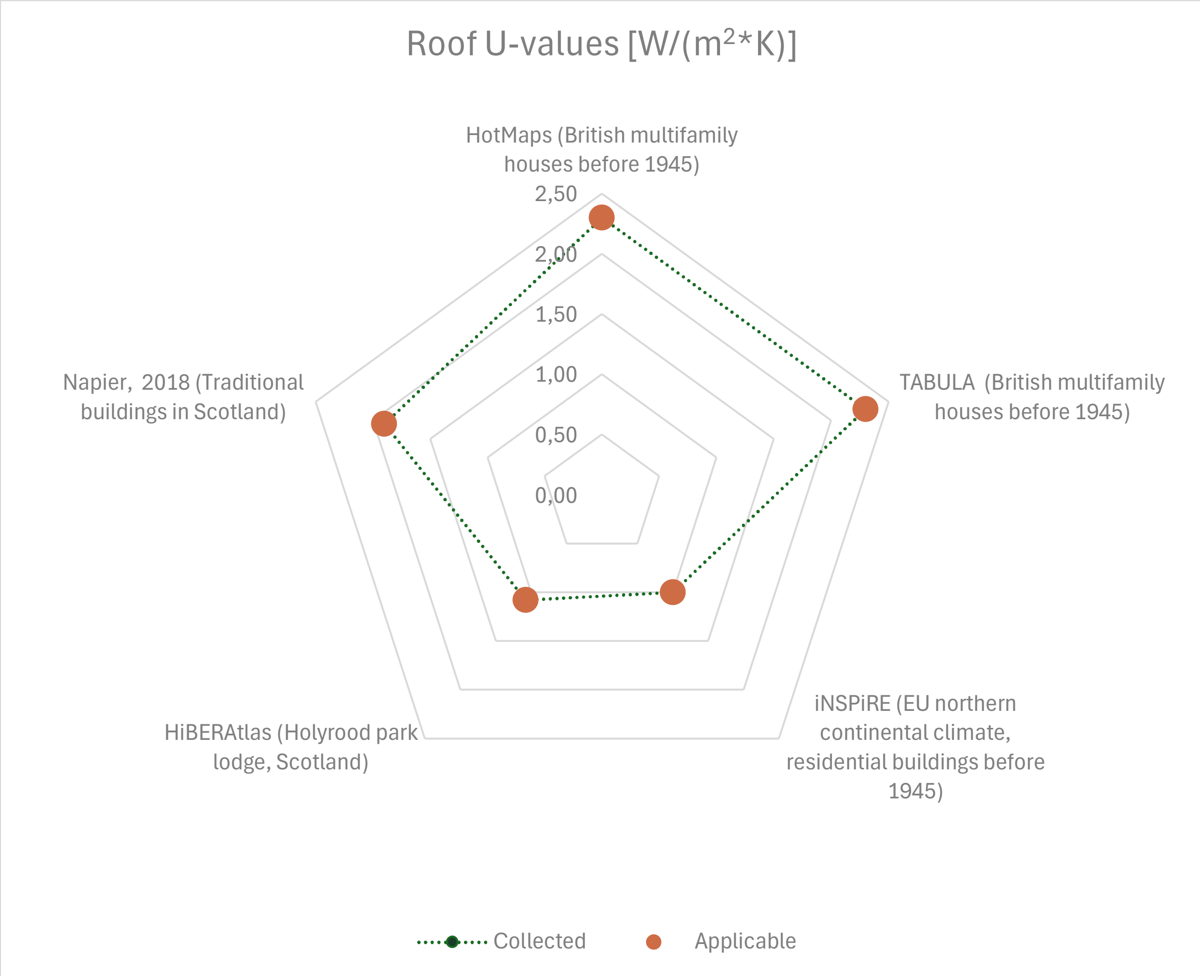


Figure 66. U-values identified for roofs of buildings with similar features to the typology "Georgian tenement".

Floor

Figure 67 provides an overview of the data collected to define a U-value range for the floor of this typology. These floors are usually built of timber structure. The values extracted from Hotmaps and TABULA have been excluded as they are too low to represent the original construction type. The range identified for the floor of this typology is **1,60-3,90 W/(m²*K).**

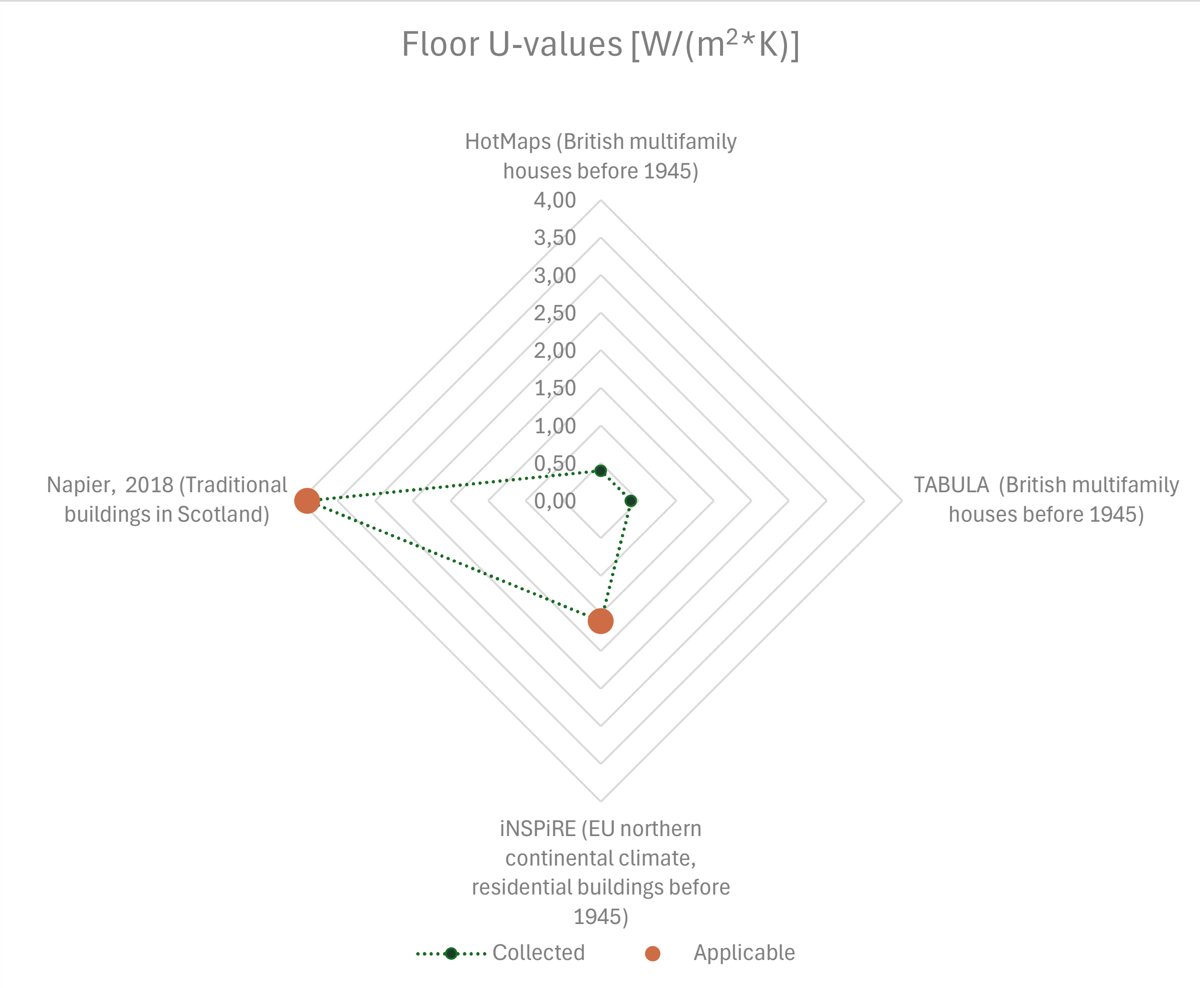


Figure 67. U-values identified for floors of buildings with similar features to the typology "Georgian tenement".

Windows

Figure 68 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. The U-value range for the original typological element corresponds to **3,60-5,40 W/(m²*K).**

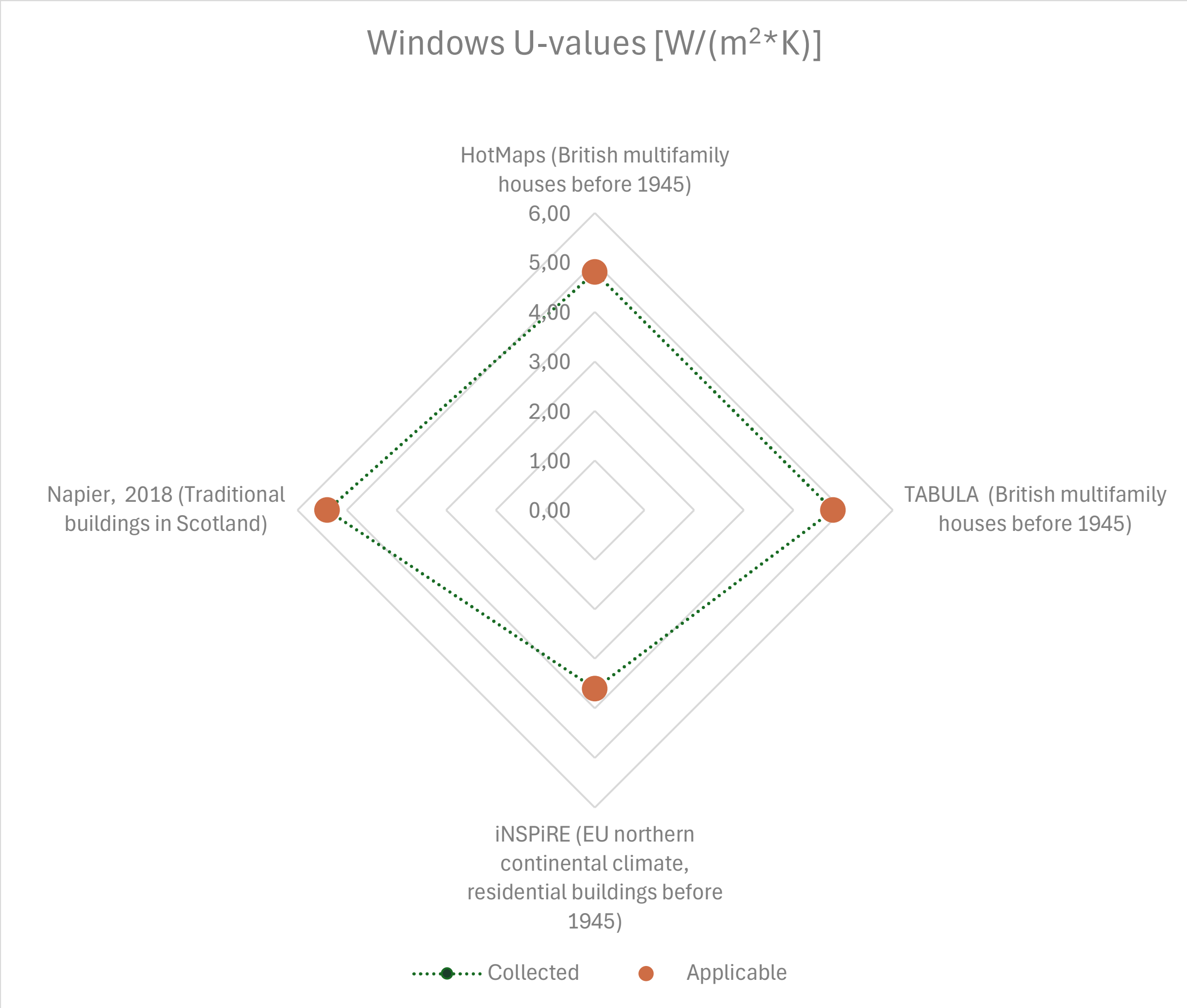


Figure 68. U-values identified for windows of buildings with similar features to the typology "Georgian tenement".

Energy demand and consumption for heating and cooling

Figure 69 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **111-290 kWh/m² year**
- Cooling: **24-46 kWh/m² year**
- Heating and cooling: **135-172 kWh/m² year**

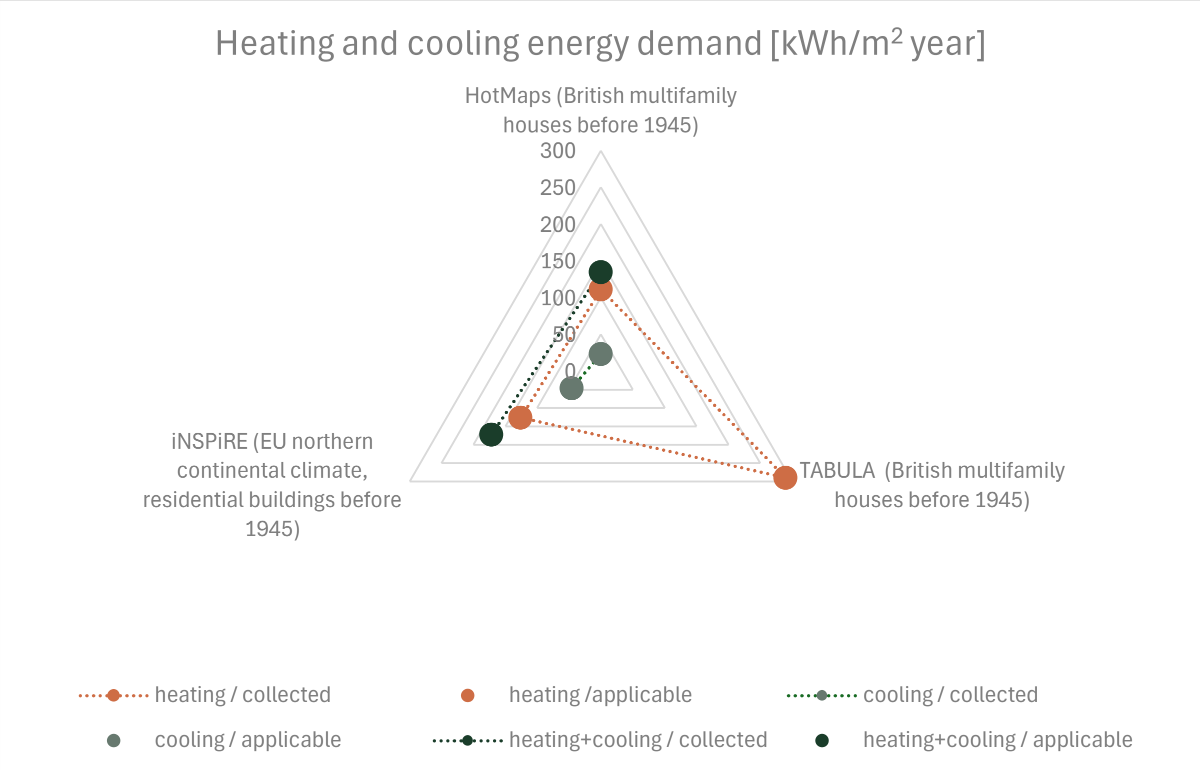


Figure 69. Energy demand data for heating and cooling identified for buildings with similar features to the typology "Georgian tenement".

Hotmaps (2020) also provided the following data about the energy consumptions of multifamily buildings realized in UK before 1945:

- Heating: **141 kWh/m² year**
- Cooling: **4 kWh/m² year**
- Heating and cooling: **145 kWh/m² year**

3.11. Victorian terraced house: Scottish Victorian terraced house (1850-1920)

3.11.1. Contextualization of the typology

Origin and diffusion

In pre-Georgian Edinburgh, tenement buildings dominated the urban landscape, shaped by the city's crowded layout within its boundary walls. Surviving houses from that era are primarily located in the Canongate area, which was, at the time, just outside the historic borders of the city. Pre-Georgian houses are usually detached or semi-detached. Notable examples include Old Moray House, a 17th-century mansion, and Panmure House, which later became the residence of the renowned Scottish economist Adam Smith. Another significant example is Acheson House, a large house from the early 17th century.

In the 18th century, as Edinburgh became a key political and cultural centre, the growing middle and upper classes created a demand for housing, leading to the construction of new terraced houses. This period saw the development of the New Town, which featured many terraced houses designed with a focus on symmetry and neoclassical style. These houses are known for their tall, narrow facades, terraced arrangements, grand staircases, and decorative details. Historically, they housed wealthy merchants, professionals, and nobles, featuring spacious interiors and intricate finishes that reflected their owners' wealth.

By the 19th century, the Victorian era introduced new styles that altered the Georgian designs. While Georgian terraced houses are recognised for their classic simplicity, Victorian terraced houses showcased a richer and more varied aesthetic. In England, the Victorian period witnessed an increase in the construction of terraced houses to accommodate the growing working class in industrial cities like London, Manchester, and Bristol. These houses were built in rows to maximise land use, featuring brick construction with ornamental details, bay windows, and decorative tiles that reflected the technology of the time (Figure 70, Figure 71). Scottish terraced houses, however, were built mostly using sand stone (or in some cases granite) rather than brick. Nonetheless, Scottish and English terraced houses share similar layouts, spatial arrangements, and uses.

Figure 70. Victorian Terraced House, West End Area, Edinburgh, Source: EWHT.

Figure 71. A row of terraced Victorian houses, Edinburgh, West End Area. Source: EWHT.

In Scotland, terraced houses can be found in various cities, each showcasing distinct architectural styles and historical periods:

- Terraced houses significantly shaped the urban fabric of Edinburgh's New Town, particularly in the first and second phases of development, as well as in the Calton Hill area, Dean Estate, and the West End. These terraced houses, built during the Georgian and Victorian eras, exhibit a range of styles, with Victorian terraced houses mainly concentrated in the West End and Dean Estate.

- Glasgow features fine examples, particularly in the West End, including neighbourhoods like Kelvingrove and the city centre. Inverness also has numerous Victorian terraced houses in its historic centre.

- In Aberdeen, notable Victorian terraced houses can be found in Ferryhill and Rosemount. Dundee has examples along South Tay Street and around the University of Dundee, with both Georgian and some surviving Victorian styles on Windsor Street.

- Perth boasts fine Georgian terraced houses, especially on Marshall Place, as well as in the city centre on George Street and St John Street, with some late 19th-century houses on James Street.

Overall, terraced houses in Scotland represent a rich architectural heritage that highlights the historic contexts of various regions. They serve not only as residential spaces but also as cultural landmarks, illustrating the evolution of Scotland's urban development.

As already presented in the contextualization of the Georgian cottage typology, the data extracted from the dataset of the Hotmaps project (2020) indicates that single-family houses (detached and terraced) realized before 1945 correspond to **5,34%** of the buildings in the UK. Furthermore, the dwellings corresponding to single family houses realized before 1945 constitute **7,12%** of the dwellings recorded in the UK.

Housing survey conducted at UK and Scottish level provided more quantitative data to assess the representativeness of terraced houses. According to the Scottish Housing Condition Survey (2017), the total number of the pre-1919 dwellings in Scotland is 473,000 of which 70,000 terraced houses. The Scottish Housing Condition Survey also shows that the number of the pre-1919 dwellings in Edinburgh is 80,000 of which 9,000 terraced houses. According to the Scottish House Condition Survey 2017, the number of dwellings of all types in Scotland is 2,603,174. Hence, terraced houses ratio to all dwelling types in Scotland is **4,37%.** Edinburgh's pre-1919 terraced houses correspond to 0.35% of Scottish dwellings.

According to the Bre Trust report on the Housing Stock of The United Kingdom (2020), the total number of the pre-1919 dwellings in the UK is 5,871,000.

The above statistics suggests the following analysis:

- UK scale:
  - Scotland's pre-1919 building stock consists 8.06% of the of the overall UK pre-1919 building stock
  - Scotland's pre-1919 terraced houses stock consists 1.19% of the overall UK pre-1919 building stock
- Scotland scale:
  - Edinburgh's pre-1919 building stock consists 16.91% of Scotland's pre-1919 building stock.
  - Edinburgh's pre-1919 terraced houses stock consists 1.90% of Scotland's pre-1919 building stock.

Architectural features

Traditional terraced houses in Edinburgh are distinguished by their elegant architectural characteristics, influenced by Georgian and Victorian styles. These houses are typically constructed from local sandstone. The façades often feature either a symmetrical (Georgian) or asymmetrical (Victorian) design, with tall, narrow proportions and grand sash and case windows framed by decorative stonework. The pane arrangement of sash and case windows depends on the architectural style/period: six over six for Georgian style and one over one for Victorian style. The entrances are marked by doorways, often with elaborate surrounds and fanlights, leading to a hallway. In the Victorian era, many terraced houses incorporated bay windows and more generally one over one sash and case windows, which enhance both light and space in the interiors. Inside, high ceilings and spacious rooms are common, adorned with intricate cornices and mouldings, while traditional fireplaces serve as focal points. The overall aesthetic reflects a blend of sophistication and functionality, showcasing the craftsmanship and style that define Edinburgh's architectural heritage.

Terraced houses are typically three storeys high, with living spaces arranged vertically, often including a basement and an attic. Ground and first floor accommodate living area, second and attic floors for bedrooms and office space. Behind the main door, there is a lobby area that provide a buffer zone before entering the house indoor spaces. The basement accommodates a kitchen and related rooms. The front façade features canted bay window, fanlight over main door, sash and case windows plus dormers which provide day light. To the back, light enters from the sash and case windows overseeing the backyard. Large sash and case windows also play a critical role in providing ventilation. Usually, there is a cupola over the stairwell to give natural light from the roof level and ventilation.

As part of a terrace, a Victorian terraced house is exposed to outdoor elements from the front and back. The design of the front facade is carefully planned to effectively redirect water away from the masonry. This is achieved through the incorporation of various architectural details, including a base course, band course, and cornices on the ground floor. On the first floor, the design features a string course, banded eaves course, cornice, and balustrade. The door piece is adorned with a consoled cornice, pilasters, and a depressed arch opening. Additionally, the window above the door is embellished with a consoled cornice and margins.

Victorian terraced houses feature mansard roofs with Scottish slates on the pitched parts. The shallow slope or flat part of the roofs are usually finished with lead sheets. The roof materials provide protection from rain and water ingress; however, to do so, they require regular maintenance. The roofs are also equipped with front and back rainwater goods consists of parapet gutters and cast iron downpipes to channel the rainwater away from the roof.

The durability and detailing of the masonry provide protection from rainwater. The building masonry construction consists of thick stone work around 600 mm thick with lath and plaster from the inside. This wall composition provides good insulation. Many terraced houses are part of a terrace, sharing walls with neighbouring houses, which helps minimise their heat loss and maximise space in urban settings. The arrangement of terraced houses in terraces provides a uniform architectural style that contributes to the city's aesthetic, creating visually appealing streetscapes with a sense of order and symmetry. This form of housing allows for efficient land use while maintaining a cohesive streetscape.

Most of New Town terraced houses do not have front garden, hence, the front façades are usually exposed to the climate elements. The big sash and case windows at the front and back could provide some solar gain during summertime, but also, contribute to energy loss through their single glazed panes in winter and cold season.

The architectural styles of terraced houses in Edinburgh are primarily influenced by Georgian and Victorian design. The Georgian style is characterised by symmetry, proportion, and classical details, including cornices and pilasters, with sash and case windows featuring multiple panes. The Victorian style is more eclectic and ornate, often incorporating bay windows, decorative stonework, and varied rooflines. This style may also include distinctive elements such as turrets and gables, showcasing a greater diversity in design and ornamentation.

3.11.2. Defining features of the typology

Table 23. Defining features of Scottish typology "Victorian terraced house".

Type	Nr	Feature	Definition of the feature
General information	1	Construction period	*1850-1920*
	2	Climate	*Cfc and Cfp Köppen-Geiger climate class*
	3	Original use	*Residential*
	4	Context	*Urban*
Geometric parameters	5	Footprint shape	*I-shape (i.e., rectangular)*
	6	Footprint area (range)	• *Small (<150 m^2)* • *Medium (150<>300 m2)*
	7	Floor surface area (range)	• *Medium (200<>1000 m^2)*
	8	Situation	*Infill (adjoining buildings on two or more sides)*
Architectural characteristics	9	Architectural Style	*Victorian neoclassical*
	10	Envelope construction	• *Sandstone walls (~60cm-thick), ashlar to the front and rubble to the rear* • *Mansard roof with timber structure, finished with lead sheets and Scottish slates* • *Suspended timber floors* • *Timber sash and case window with plated glass.*
	11	WWR (range)	*Small (<20%)*
	12	Space organization/natural light/bioclimatic aspects/ internal circulation scheme	• *Canted bay window house of three storeys with an attic and a basement.* • *Ground and first floor accommodate living area, second and attic floors for bedrooms and office space* • *Basement for kitchen* • *Large sash and case windows provide day light from both facades and ventilation.* • *Usually there is a cupola over the stairwell to give natural light from the roof level and ventilation.* • *The design of the front facade is carefully planned to effectively redirect water away from the masonry.*
Heritage attributes	13	Heritage attributes to be preserved	• *Façade and materials* • *Original sash and case windows* • *Front doors and fanlight* • *External railings and platts at the front* • *Roof design and materials* • *Internal heritage features (cornices, chimneys, staircase, etc.)* • *Internal layout/distribution and function of the rooms (for the best-preserved examples)* • *Bay windows*

3.11.3. Variable features of the typology

Table 24. Variable features of Scottish typology "Victorian terraced house".

Type	Nr	Feature	Definition of the feature
Occupancy	14	Occupancy	*Permanent*
Spatial situation	15	Surroundings	*Backyard*
	16	Buffer spaces	• *Attic* • *Basement*
Heritage values	17	Typical level of protection	*Medium (National interest)*
	18	Conservation area	*Yes*
	19	Authenticity (1:max-5:min)	*2*
	20	Integrity (1:max-5:min)	*2*
	21	Rarity (1:max-5:min)	*5*
	22	Representativeness (1:max-5:min)	*1*
	23	Interests	• *Aesthetic* • *Technical* • *Architectural* • *Historic* • *Urban Planning*

3.11.4. Energy performance of the typology

Performance of building envelope elements

Walls

Figure 72 provides an overview of the data collected from various sources to define a U-value range for the walls of this typology. Most of the exterior walls of this typology are built of natural stone. For this reason, data extracted from Hotmaps and TABULA has been excluded as it refers to brickwork walls. Based on the data applicable to this construction, the U-value range generated for the walls of this typology is **1,30-2,32 W/(m²*K).**

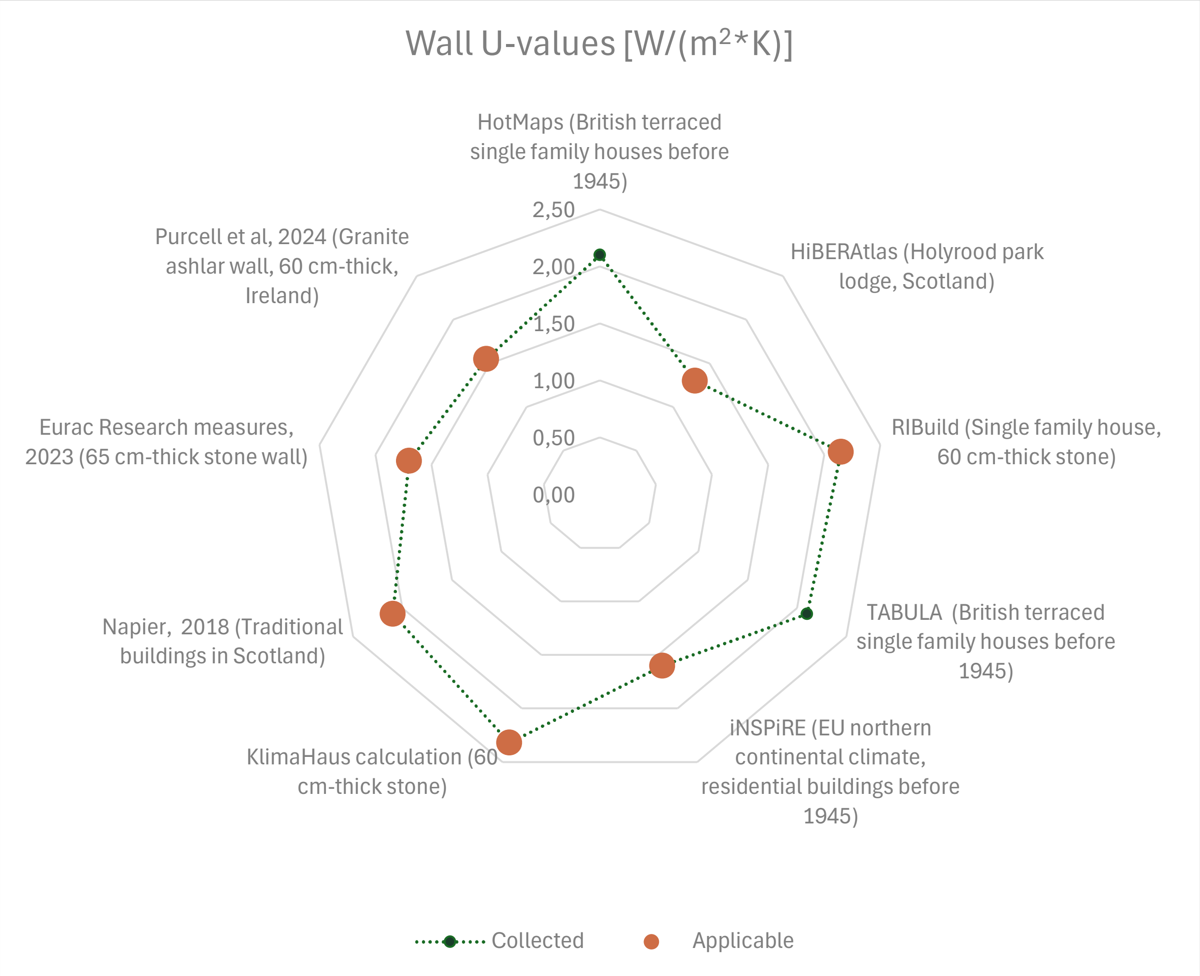


Figure 72. U-values identified for walls of buildings with similar features to the typology "Victorian terraced house".

Roof

Figure 73 provides an overview of the data collected to define a U-value range for the roof of this typology. The original roof construction associated with this typology consists of timber structure. The U-value range generated for the roof of this typology is **1,00-2,30 W/(m²*K).**

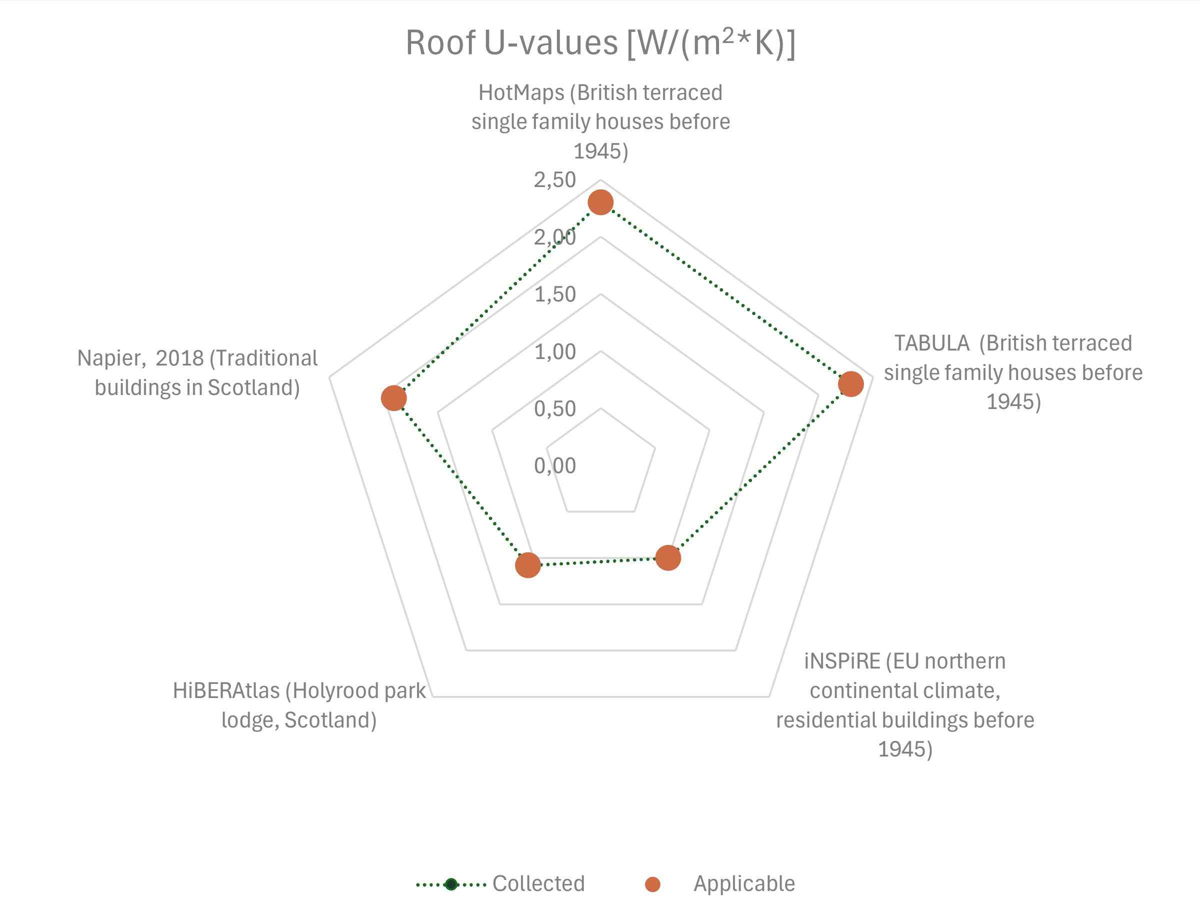


Figure 73. U-values identified for roofs of buildings with similar features to the typology "Victorian terraced house".

Floor

Figure 74 provides an overview of the data collected to define a U-value range for the floor of this typology. These floors are usually built of timber structure. The values extracted from Hotmaps and TABULA have been excluded as they are too low to represent the original construction type. The range identified for the floor of this typology is **1,60-3,90 W/(m²*K).**

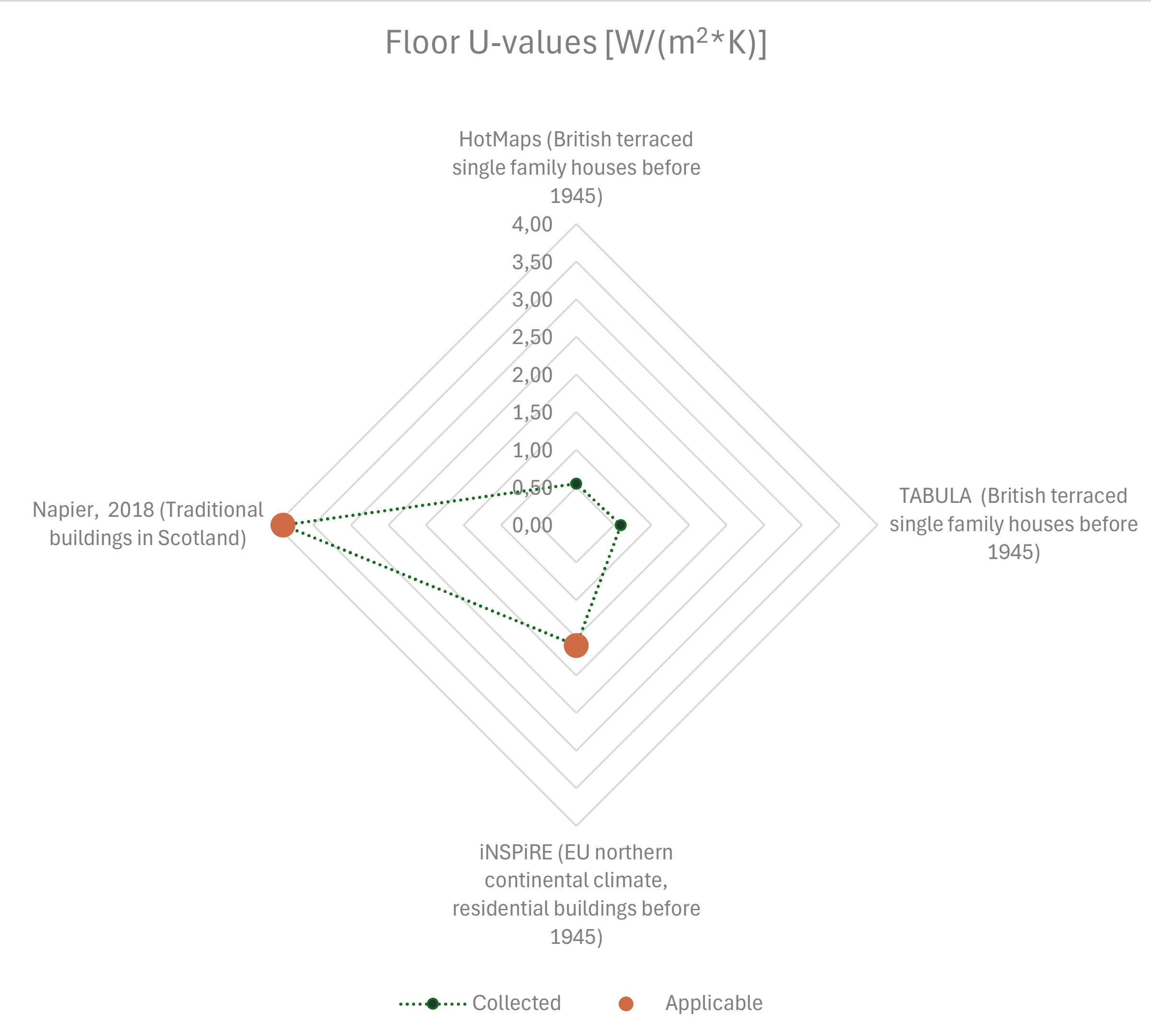


Figure 74. U-values identified for floors of buildings with similar features to the typology "Victorian terraced house".

Windows

Figure 75 provides an overview of the data collected to define a U-value range for the windows of this typology. The windows of this typology are built of wooden frames and single glazing. The U-value range for the original typological element corresponds to **3,00-5,40 W/(m²*K).**

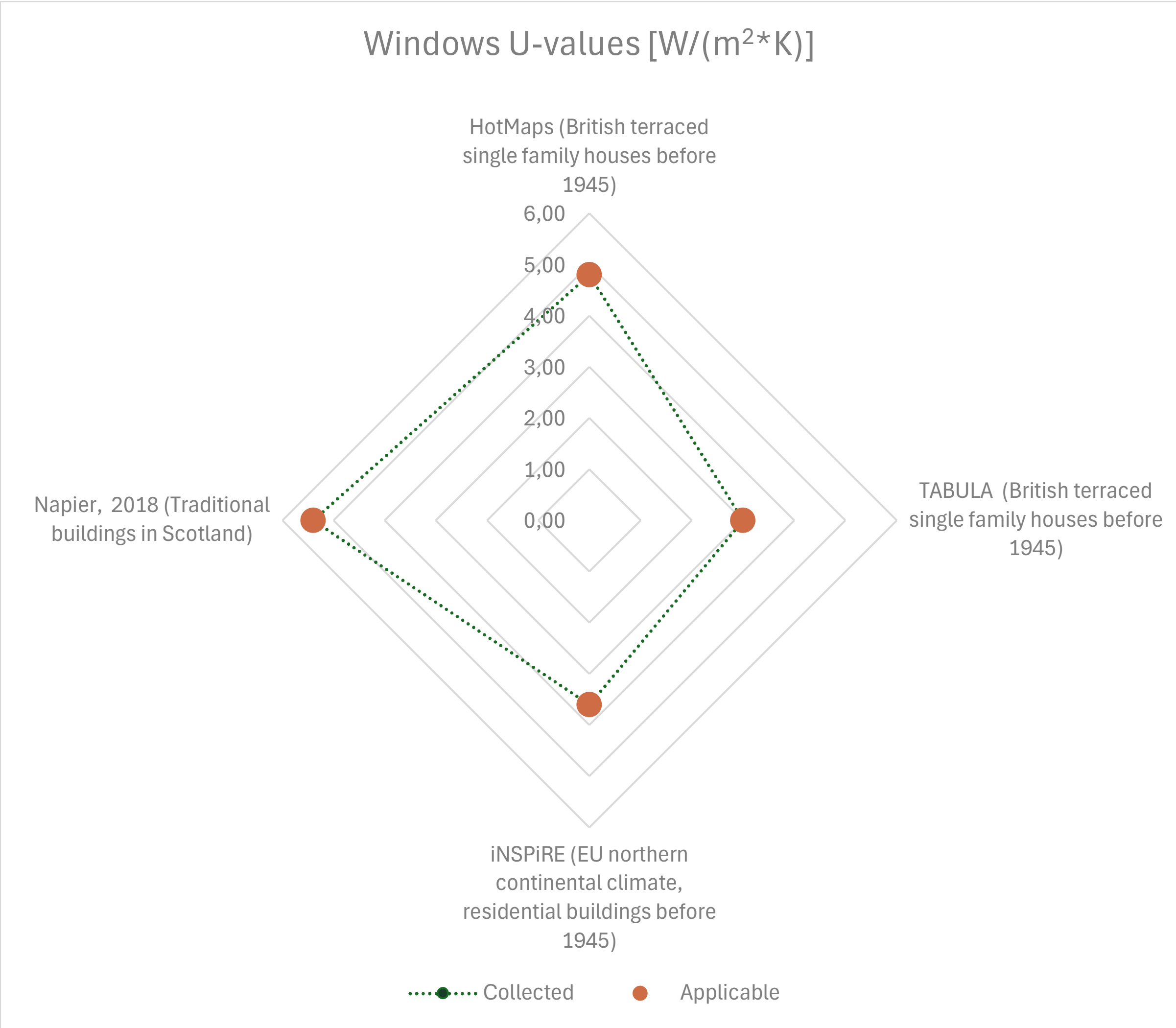


Figure 75. U-values identified for windows of buildings with similar features to the typology "Victorian terraced house".

Energy demand and consumption for heating and cooling

Figure 76 provides an overview of the data collected to define a range for the energy demand for heating and cooling of this typology. The ranges identified for energy demand are the following:

- Heating: **126-211 kWh/m² year**
- Cooling: **24-36 kWh/m² year**
- Heating and cooling: **162-234 kWh/m² year**

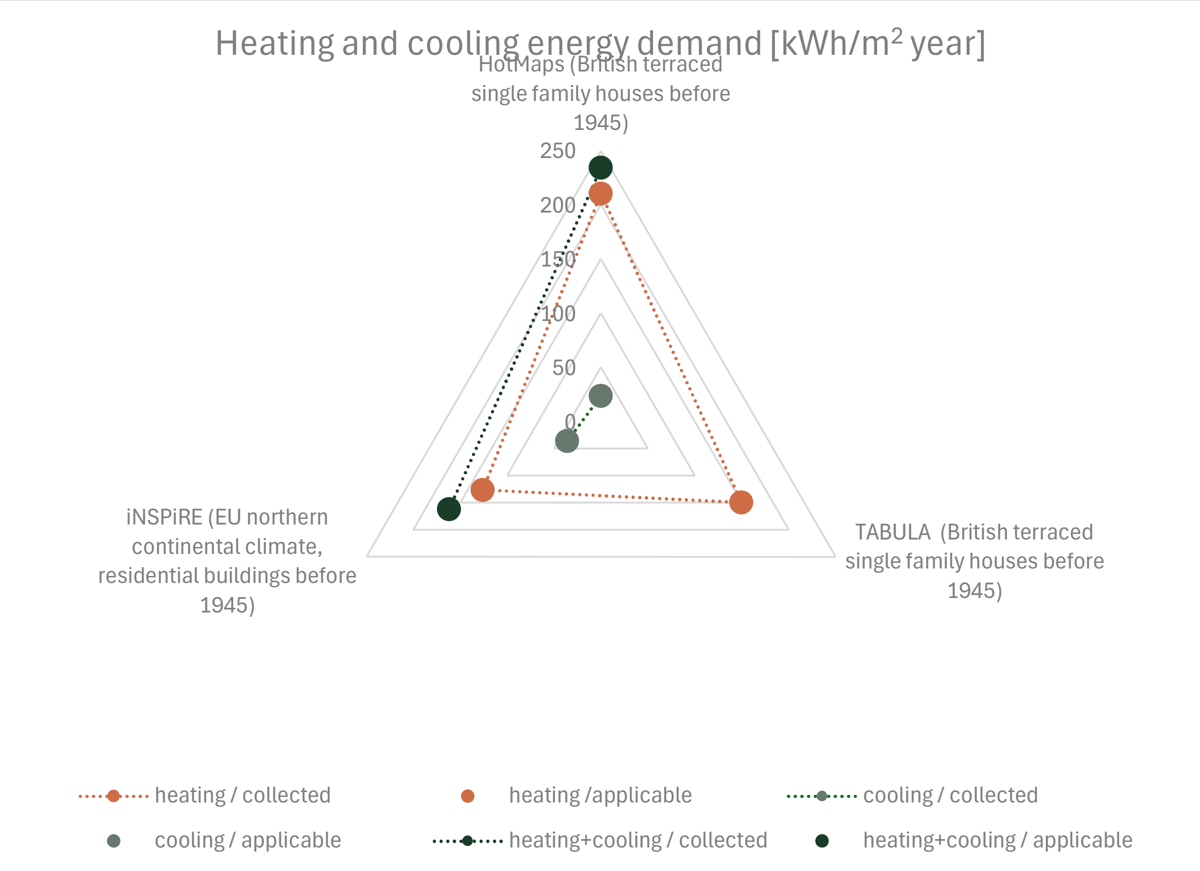


Figure 76. Energy demand data for heating and cooling identified for buildings with similar features to the typology "Victorian terraced house".

Hotmaps (2020) also provided the following data about the energy consumptions of single-family houses realized in the UK before 1945:

- Heating: **268 kWh/m² year**
- Cooling: **4 kWh/m² year**
- Heating and cooling: **271 kWh/m² year**

3.12. Potential applications and limitations of results

3.12.1. Defining and variable features

The method implemented to define typologies of historic buildings in FuturHist has addressed the existing gap between "synthetic average" typology approaches (IEE Project TABULA, 2009-2012) and case study-based characterisation of the historic building stock.

Existing dataset on EU building stock (BSO, 2024; Moderate, 2022; Hotmaps, 2020) consider all buildings erected before 1945 in one single age class, categorising them according to sector and use. In this task, historic building typologies have been defined using 13 features that allow to differentiate buildings erected before 1945. These features include general information (1-4), geometric parameters (5-8), architectural characteristics (9-12) and heritage elements to be preserved (13). Multiple choice parameters were favoured to express the features; however, three features remain open ended (i.e., architectural style, envelope construction, space layout/natural light/bioclimatic aspects/internal circulation scheme). These parameters constitute an input for the development of the toolkit in WP4. Obviously, open ended features can generate a lot of different subcategories; thus, increasing the complexity of a toolkit or hindering its potential for replicability. Therefore, not all the features may be integrated in the toolkit and a simplification of the typologies may be required. WP6 is meant to test the replication of this typology-based approach; thus, providing the basis to assess the effectiveness of the defined features.

The 13 defining features refer to the characteristics of the historic buildings in their original state, i.e. when originally designed/constructed. This choice allowed to simplify the definition of typology by leaving out the characteristics that are related to the current configuration of the building (i.e., their use, their transformation over time and their heritage protection status). Nevertheless, these factors can significantly influence the scope of retrofitting interventions. The inclusion of defining features related to the current configuration of historic buildings would generate an exponential number of sub-typologies for each defined typology, which would increase even more the complexity of a toolkit in WP4. For this reason, a set of 11 variable features has been laid out to describe recurring, but non-unique, characteristics of each typology. These additional parameters allow to set the scope of the different retrofit solutions developed in WP2 and WP3 and tested in WP5 for the typologies associated with the demonstrator buildings. Furthermore, these additional parameters also constitute an input for the development of the toolkit in WP4.

3.12.2. Defined typologies

The implementation of sets of defining and variable features of the typologies allows to compare the nine typologies used in the project. Four typologies are terraced tenement buildings (casa de pisos, patio de vecinos, Kamienica, Georgian tenement), three typologies are single-family houses (willa miejska, Georgian cottage, Victorian terraced house), one is a housing building (Flerbostadshus funktionalism), and one is a public building (Monumentalbyggnad).

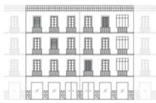
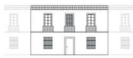
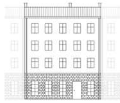
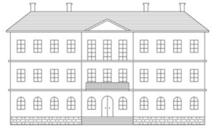
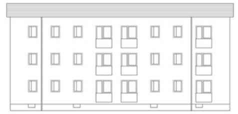
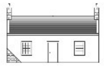
Terraced tenement buildings represent one of the most common typologies of buildings located in the historic centres of eldest European cities. Furthermore, terraced tenement buildings located in Scotland and Poland share similarities due to comparable climate conditions. Conversely, terraced tenements located in Spain were developed to cope with a warmer climate context. However, the use of material differs from one country to the other depending on the resources available at that time and the socio-economic context.

Similarities can be identified between the Georgian cottage and the Victorian terraced house in terms of building materials and construction methods. Conversely, the willa miejska (located in a comparable climate context) is significantly different from the Scottish single-family houses in terms of layout, building materials and construction technologies. That is because it was developed in a different time and in a very different socio-economic context.

Challenges associated with the quantification of buildings belonging to the defined typologies within the national building stock result from lack of detailed datasets (often typologies are defined by form – detached, terraced house, tenement – or household type – single or multiple-family house). There is almost no data available when considering specific period/architectural style. As a result, the statistic used are often too general and include other buildings typologies than the ones identified in the project.

The ranges generated for quantifying the performance of each typology allow to compare them in terms of energy efficiency. Table 25 offers an overview of the performance ranges generated for the different elements of the building envelope as well as for the energy demand and consumption for heating and cooling of each typology.

Table 25. Performance ranges generated for the building envelope elements as well as energy demand and consumption for heating and cooling of each typology

Typology	1	2	3	4	5	6	7	8	9
Name	Casa de pisos	Patio de vecinos	Kamienica	Willa miejska	Monumentalbyggnad	Flerbostadshus funktionalism	Georgian cottage	Georgian tenement	Victorian terraced house
Icon									
Wall U-value range [W/m²K]	0,76-2,75	1,37-2,23	1,00-1,60	1,10-1,55	0,60-1,31	0,58-2,23	1,30-2,32	1,30-2,32	1,30-2,32
Roof U-value range [W/m²K]	1,73-5,00	1,73-5,00	0,90-2,70	0,70-1,10	0,40-0,77	0,36-0,50	1,00-2,30	1,00-2,30	1,00-2,30
Floor U-value range [W/m²K]	1,07-2,60	1,19-2,60	0,72-1,60	0,72-2,20	0,40-0,50	0,30-0,40	1,60-3,90	1,60-3,90	1,60-3,90
Windows U-value range [W/m²K]	3,92- 5,47	3,92- 5,47	3,18- 5,00	3,18- 5,00	2,30- 3,20	2,22-3,20	3,60-5,40	3,60-5,40	3,60-5,40
Heating demand [kWh/m²year]	59-123	59-123	126-187	126-313	120-226	79-183	126-211	111-290	126-211
Cooling demand [kWh/m²year]	50-70	50-70	36	32-36	23-55	14-27	24-36	24-46	24-36
Heating consumption [kWh/m²year]	101-210	101-210	145-199	256-364	98-228	77-231	268	141	268
Cooling consumption [kWh/m²year]	15-20	15-20	3-4	4-5	10-23	4	4	4	4

The performance ranges also constitute inputs for different WPs. The range-based approach is to be considered also to include energy performance-related parameters in the toolkit in WP4. The use of ranges (instead of average values) allows to represent the variability of historic buildings belonging to the same typology. However, working with ranges implies increasing the complexity of calculation-based approaches. Therefore, the replication of the typology-based approach in WP6 will be crucial to assess also the effectiveness of a range-based methodology to include quantitative performance data in a retrofitting toolkit.

The element-related ranges provide an input for the development of typology-based passive solutions in WP2. The ranges representing the energy demand and consumption for heating and cooling will be considered for developing typology-based active solutions in WP3. Furthermore, all the ranges they will be taken into account when setting up the simulations for assessing the potential of retrofitting measures in WP5 beyond the specifics of the demonstrator buildings.

Due to the lack of data on the energy demand and consumption of historic buildings, the ranges generated to represent energy demand and consumption are for most typologies based on average data. Therefore, the use of these ranges in other WPs will have to be handled keeping in mind their lack of refinement to avoid the production of misleading results.

4. Conclusions and Outlook

This research task has defined the typologies of historic buildings used in FuturHist and quantified their performance.

A method for defining typologies within the pre 1945 historic building stock has been drawn up starting from the features of the demonstrator buildings. As the historic building stock possesses different features compared to more recent buildings, the method that was implemented consists in the identification of typological characteristics which include material and geometrical properties, as well as historic, artistic and heritage significance. This method allowed to clearly define the nine typologies of historic buildings addressed in FuturHist:

1. Casa de pisos
2. Patio de vecinos
3. Kamienica
4. Willa miejska
5. Monumentalbyggnad
6. Flerbostadshus funktionalism
7. Georgian cottage
8. Georgian tenement
9. Victorian terraced house

The contextualisation of each typology has led to the assessment of its heritage significance and its diffusion at its national level. Even if fully comprehensive inventories of historic buildings at national level have not been retrieved for all defined building typologies, data currently available confirms the relevance of these typologies at country level. Furthermore, some of the identified typologies proved to be diffused at cross-country level in Europe.

Most historic buildings are not built with standardised construction products. In addition, their construction process was also affected by case-specific constraints (e.g., location, availability of materials, construction techniques/knowledge, etc.). For these reasons, ranges of values – rather than average values – were used to quantify the performance of historic building typologies. The quantification of the performance of each typology included the following elements: thermal performance of the building envelope, energy demand for heating and cooling, and energy consumption for heating and cooling.

For each of the nine typologies, ranges of U-values for the main elements of the building fabric (walls, roof, floor and windows) have been defined. The U-value range corresponding to each element of the building envelope expresses the existing variability of this parameter within the boundary of each typology. The identified ranges show that the U-value ranges defined for windows are mostly aligned with the average values provided by BSO (2024) for buildings erected before 1945 classified by country, sector and use. Instead, a greater variability has been identified for walls, roofs and floors construction between different historic typologies at national levels. That is because, in some cases, the construction technologies and materials employed to build these elements in the studied typologies differ significantly from the most common ones indicated in the available datasets (Hotmaps, 2020; Moderate, 2022).

Based on the available sources for each case, ranges have been identified to represent the energy demand and consumption for heating and cooling of each typology. Due to the limited number of available data, most of the ranges identified to quantify the energy demand are wide. The amplitude of the ranges also reflects the variability of historic buildings in terms of material and geometry within each typology. However, historic buildings were not designed to be heated and cooled by means of mechanical systems and – more importantly – were not meant to meet today’s comfort standards. Therefore, this result suggest that an accurate classification of historic buildings based on their energy demand (calculated according to current standardized calculation methods) may not be reliable. The same conclusion applies to the quantification of energy consumptions. In fact, data collected about energy consumption for heating and cooling is, for most typologies, limited to average values. However, when available, measured values on real buildings belonging to each typology can be used to establish ranges. Theses ranges allow the integration of the impact of user behaviour and buildings systems when quantifying the energy performance of each typology.

Data collected from the monitoring already done for the demonstrator buildings located in Spain, Poland and Sweden has provided useful inputs to define a monitoring program for all demonstrator buildings. The monitoring program for the demonstrator buildings developed in this task will help generate data about the current performance of these buildings. This data will be used in WP2, WP3 and WP5.

The results of this task provide a robust basis for the use of typologies within the different interconnected FuturHist WPs. First, the demonstrator buildings have been associated with clearly defined buildings typologies. This ensures that the retrofit solutions developed in WP2 and WP3, and tested in WP5, can be linked to the typological features of each demonstrator building – and not only limited to building-specific parameters. Second, the method developed to define typologies within the historic building stock provides a set of indicators for tailoring the integrated planning toolkit implemented in WP4. Third, four additional building typologies have been defined in this task; they will be used in WP6 to develop, test and validate the guidelines that will enable the replication of the typology-based approach developed in FuturHist.

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FuturHist

Tailored intervention solutions for future-proofing historic buildings

At FuturHist, we research and test energy-efficient retrofit interventions tailored to historic building typologies. We implement these solutions in real-life demonstration cases in Poland, Spain, Sweden and the UK. We focus on innovative solutions such as bio-based materials, internal insulation systems, window retrofits, HVAC, and RES integration.

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