Unlocking Energy Efficiency in the Italian Public Housing Legacy: A Typological Blueprint for Cost-Effective Retrofitting

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Abstract. Improving the energy efficiency of existing buildings through retrofitting interventions is essential to reduce energy consumption and mitigate climate change impacts. However, implementing effective retrofit strategies requires a deep and comprehensive analysis of the existing residential building stock. Our research work focuses on the Italian Public Residential Building stock (PRB) built between 1950 and 1980. During this historical period, attention to energy performance was not a priority, resulting in low thermal efficiency. Building on previous efforts such as the TABULA and EPISCOPE projects, which provided a taxonomy of harmonized European residential typologies, this study aims to develop a detailed and refined typological analysis specific to the public residential building sector in Italy. The methodology involves an extensive literature review to create a comprehensive database incorporating parameters such as building geometry, construction materials, energy systems and climate conditions. This database allows the identification and definition of distinct PRB typologies based on planimetric configurations, volumetric characteristics and aggregation patterns. This typological taxonomy will serve as a basis for the future implementation of a "retrofit intervention matrix" to assess the cost-effectiveness of various retrofit strategies in different typologies.

Keywords: Building Typology · Energy Retrofit · Public Residential Building stock · TABULA

1 Introduction

The building sector accounts for a significant portion of global energy consumption and greenhouse gas emissions. In the European Union, buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions [1]. Improving the energy efficiency of existing buildings through retrofitting is critical for lowering energy consumption, combating climate change [2–4]. But implementing effective retrofit strategies calls for a comprehensive knowledge of the building′s features, energy

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performance, and related expenses. Underfunded by the Intelligent Energy Europe Program from 2009–2012, the TABULA (Typology Approach for BUiLding stock energy Assessment) project sought to create a harmonized framework for European residential building typologies to support energy performance calculations and retrofit strategies. Comprising building typology data for 13 European nations categorized based on age, size, and construction type, the TABULA project developed a web tool. This gave a structure for assessing possible energy-saving retrofit strategies and approximating the energy performance of several kinds of residential buildings [5, 6]. Building upon TABULA, the subsequent EPISCOPE (Energy Performance Indicator tracking Schemes for the Continuous Optimization of refurbishment Processes in European housing stocks) project from 2013–2016, also funded by Intelligent Energy Europe, further developed and expanded this harmonized typology approach. EPISCOPE aimed to monitor building stock energy performance and refurbishment rates, as well as optimize renovation processes across European housing sectors [7, 8]. EPISCOPE initially used the TABULA typologies but improved and integrated them with additional parameters such as energy vectors and systems to better represent the variety of architectural features influencing energy use [9]. To more accurately estimate energy performance and evaluate renovation measures for particular building typologies, these two complementary projects offered a thorough and crucial framework for classifying residential buildings according to their size, age, construction type, energy systems, and other important parameters.

However, while TABULA and EPISCOPE have laid the general foundations for the analysis of residential building typology, there is a need for more detailed and specific investigations, especially for the public residential sector. Public residential buildings (PRBs) play an important and primary role in the Italian national context in addressing housing needs in situations of economic hardship. Many PRBs in Italy were in fact built between the 1950s and 1980s, before the introduction of national energy regulations (e.g., Law 373/1976), a period in which energy efficiency was not a primary concern, resulting in poor thermal performance and high energy consumption [10–15]. Building upon the foundations established by the TABULA and EPISCOPE projects, this contribution is part of a multi-phase project aimed at analyzing the costs of energy retrofit interventions applied to Italian PRBs constructed between 1950 and 1980. In this contribution, we will present Phase I of the project, which focuses on i) analyzing the existing PRB stock, and ii) defining a reference database that includes 2,115 PRBs models. A detailed database and analysis of retrofit costs will be beneficial to policymakers, building owners and all parties involved in planning and implementing energy-efficient retrofits for PRBs [16–18]. These findings will be particularly crucial given the recent implementation of incentive policies in Italy aimed at improving building energy efficiency [19–22], supporting the design of customized incentive schemes and policies that address the unique challenges of low-income households living in energy-inefficient PRBs.

2 PRB Stock: The Italian Case

Following World War II, Italy faced a severe housing shortage, with many urban areas devastated and a rapidly growing population. To address this crisis, in 1949, the Italian government launched the INA-Casa (Istituto Nazionale delle Assicurazioni) program. This was an ambitious public housing initiative aimed at stimulating construction, providing employment, and developing affordable housing for low-income families [23]. The INA-Casa program was structured into two seven-year phases spanning from 1949 to 1963. During this period, numerous public housing projects were constructed across Italy following architectural and urban planning guidelines, compiled in four booklets [24]. These series of "Suggestions, norms, and schemes" for building and urban planning proved useful both in the initial phase of competitions for selecting designers to be included in the INA-Casa lists and in the subsequent project drafting phase. Although intended as "recommendations", these guideline booklets effectively functioned as actual norms [25]. The first two booklets were published in 1949 and 1950, aiming to provide designers with schemes, illustrated examples, advice, and warnings. These documents were later updated and republished in 1956 in anticipation of the INA-Casa Plan extension. The first booklet summarizes the Plan′s fundamental principles. The suggestions mainly concerned the approach to being taken on projects from an economic perspective and the need to achieve a balance between various requirements. These included avoiding any superfluous expenses by studying room dimensions and space utilization to achieve perfect functionality. As well as the need to conceptualize the project to obtain adequate building exploitation, good living conditions, and a high level of formal quality [24]. Furthermore, there was a desire for the Plan′s housing to be "psychological housing," aimed at creating the best environmental conditions for workers' lives, both in neighborhood creation and housing realization. It was thus prescribed that projects should thoroughly study technical and architectural details from constructive, economic, and human perspectives. These guidelines also introduced the concept of "building types" (detached houses, terraced houses, blocks, etc.). Building types were used to schematically define shapes along with housing capacity (1, 2, or 3 bedrooms) and living habits (about the kitchen-living room-dining room relationship). The identified building types were: i) Continuous multi-story building with 2 apartments per floor-staircase; ii) Isolated multi-unit building with two apartments per floor; iii) Single-story row house; iv) Two-story row house. Interestingly, the described "building types" are actually very generic, allowing great freedom for designers. There is no characterization of buildings in terms of plan-volumetric configuration, dimensions relative to the total number of apartments, etc. It is not specified what is meant by "continuous multi-story building" or "isolated multi-unit building." The Booklets, therefore, deal with "building types" with the aim of giving recognizable characteristics to INA-Casa buildings and somehow guaranteeing certain building standards, as well as urban planning standards. The system adopted by INA-Casa, of entrusting the conception of neighborhoods and buildings to freelance professionals, was designed to give the complex of constructions a unitary imprint, in urban, technical, economic, and social terms. However, while providing essential accommodation, numerous of these buildings were constructed with minimal attention to thermal efficiency, resulting in substandard thermal performance and elevated energy ingestion [26, 27]. Today, the aging RPSs stock represents a major

challenge regarding energetic deprivation. People living in government apartments are at high risk because these buildings usually have poor insulation, old heating equipment, and other energy waste issues [28–32].

3 Materials and Method

This contribution concerns the first Phase of larger and extensive research which is divided into three sequential Phases, as illustrated in Fig. 1

I. Literature analysis of the public residential heritage and its classification, followed by direct analysis of the same and the creation of a reference database.
II. The identification, definition and application of a matrix of energy requalification strategies/scenarios (ERS) to the typological case studies identified in Phase I. This phase includes Energy Performance and Class assessments for each typology.
III. The assessment of the costs of such ERS, to be related to the energy class leap obtained.

As mentioned, this contribution presents the results obtained at the end of Phase I of the research. Extensive bibliographic research and integrative analyses were developed to catalogue the buildings according to a series of parameters, including first the construction period, the building typology, the planimetric configuration, building geometry, the construction materials, energy systems, climatic conditions, etc. Following this subphase, the generation of a Database consultable via pivot tables for the facilitated extrapolation of data was created. Through this approach, in Phase I, the research aims were to achieve the following two objectives:

1. Develop a comprehensive and structured database of Italian PRBs constructed between 1950 and 1980, incorporating detailed information of 2,115 buildings.
2. Refine the building typology classification by identifying and defining specific and unique features across the sample.

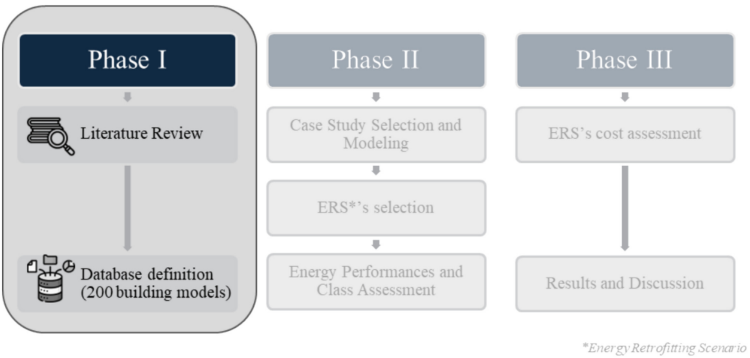


Fig. 1. Research Phases

Literature review, which included bibliographic sources, supplemented by archival sources and freely accessible online databases, revealed a lack of systematic and functional organization of information/data. Various texts collect data in a mostly descriptive manner, with tabular information primarily focusing on the number of housing units built in different provinces and years, and macro-scale costs incurred by INA-Casa over various seven-year periods. However, there′s a notable absence of summarized geometric, typological, and constructive data, resulting in a lack of detailed and specific insights into the constructed properties. Instead, greater emphasis is placed on constructions as "Neighborhoods" with certain urban parameters and planned community services.

The research aimed to systematize data, extracting crucial information to create a comprehensive and updatable knowledge framework of ERP (Public Residential Housing). These considerations led to the development of an expandable DATABASE that collects, integrates, and processes data on ERP built in Italy between 1950 and 1980. The 2,115 buildings, included in our database, were identified by cross-referencing data from INA-CASA reports and MEF (Ministero dell′Economia e delle Finanze) databases [33]. The analysis focused on this timeframe as it represents the period of greatest ERP construction, coinciding with the development of the INA-Casa plan.

As mentioned, the parameters that define the PRB Database have been identified to describe in depth the geometric-constructive aspects of the buildings under analysis. In particular, two objectives guided the generation of this dataset:

1) to catalog the PRB heritage at a typological level,
2) to collect information to conduct energy analyses on these buildings and characterize the properties based on energy consumption.

For these reasons, the parameters used are summarized in Table 1, and fully described in detail in Table A1, reported in the appendix. The selected parameters are divided into five macro areas: Anagraphic, Geometric, Typological, Structural, and Climatic. The Anagraphic section includes identifiers, location details, and construction period information. The Geometric area covers building dimensions info, including e.g. volume, number of stories and number of units. The Typological section focuses on building shapes, aggregation schemes, typologies, and subtypologies. The Structural portion lists parameters related to the physical structure, such as building components and materials. Finally, the Climatic area includes the climate zone and orientation details relevant to the building's environmental context.

The Access database, containing information on 2,115 buildings, was initially populated using INA-CASA reports and other bibliographic sources to enhance and support our database compilation [24, 25, 33]. These sources included existing databases, reports, academic papers and researches, and archival sources [9, 24, 34–39], providing additional information such as location details, construction periods, and architectural drawings. For data not available in these reports (e.g., dimensions, number of floors, building structure, etc.), we conducted desk research, cross-referencing cadastral information with photogrammetry data from Google Earth Pro. This tool was also used for surface area calculations and visual inspections to complement the collected information.

In the following Section, we present some results obtained from the analysis of this collected data, which provided an overview of the Italian PRB stock. Finally, a comparison was made with the database previously proposed by TABULA.

Table 1. Parameters detected for each ERP building analyzed

PARAMETERS	DATA				
	Anagraphic	**Geometric**	**Typological**	**Structural**	**Climatic**
	Building *ID#*	*Dimension*	*Stairwell Position*	*Building Structure*	Cliamte Zone *CZ*
	District Name *DN#*	District Covered Area *DCA*	Number of Ramps *Nr*	Vertical *Vbs*	Orienta-tion *O*
	Location	Building Covered Area *BCA*	Units per Ramp *Ur*	Slab type *St*	
	Location *IDl*	Unit Cov-ered Area *UCA*	Plan Shape *PS*	Roof type *Rt*	
	City *IDc*	Gross Leasable Area *GLA*	*Aggregation scheme*	Roof finish-ing *Rf*	
	Address *IDa*	Building Perimeter *P*	Building typol-ogy *BT*	*Windows and Doors*	
	Construction Period	Dispers-ing sur-face *DS*	Building sub ty-pology *BsT*	W&D Type *WDt*	
	Start *Ys*	Sur-face/Vol-ume *SV*	Basic Module Number *BM*	W&D Blinds *WDb*	
	End *Ye*	*Stories*			
	Period *Yp*	Number of stories *NS*			
	Building Use *BU*	Residen-tial stories *RS*			
		Volume			
		District Volume *DV*			
		Building Volume *BV*			
		Number of Units			
		Number of Units per Dis-trict *NuB*			
		Number of Units per Build-ing *NuBldg*			
		Number of Units per Floor *NuF*			

4 Results and Discussion

4.1 Data Distribution

The 2,115 analyzed buildings are distributed throughout Italy, with a predominance in the north, as shown in the graph in Fig. 2 and Fig. 3a.

As mentioned earlier, the buildings analyzed were constructed between 1950 and 1980. The graph in Fig. 3b demonstrates that the period of greatest development was between the 1950s and 1960s, coinciding with the First Seven-Year Period of the INA-Casa Plan. Between the 1960s and 1970s, during the final part of the Second Seven-Year Period, fewer buildings were developed compared to the previous period. The



Fig. 2. PRBs distribution on a National Scale

subsequent period, between the 1970s and 1980s, was undoubtedly the one with the least development.

According to the D.P.R. 26 August 1993 n.412 (Table A in Annex A, updated on 24.10.2018), Italy is divided into 6 climatic zones/exposure classes based on degree-day (DD) clusters. As shown in Fig. 3c, the majority of the analyzed buildings are located in zone E.

4.2 Typological Results

A significant part of the research work involved defining the typological analysis on the PRBs sample. As previously mentioned, the study aims to determine the actual outcomes of the design process carried out during the INA-Casa Plan years, following the generic guidelines regarding "building typologies" provided by the Agency in its publications. The inclusion of buildings in the Database and their categorization according to their plan-volumetric configuration resulted in the identification of 5 building typologies that encompass the PRB stock: Terraced house (Th), Detached house (Dh), Townhouse (T), High-Rise building (HRb), and Block building (Bb).

The following table (Table 2) provides a concise description and the typical graphical configurations of the identified Building Typologies (BT), in relation to the average data of other parameters (surface area, number of floors, number of units, etc.) derived from the analysis.

The graph in Fig. 3d shows that the most prevalent building typology is the Terraced house (Th), representing 50% of the properties. This is followed by the Townhouse (T), Detached house (Dh), High-Rise building (HRb), and finally the Block building (Bb) at only 2%. For each building typology, except for the HRb, "sub-typologies"

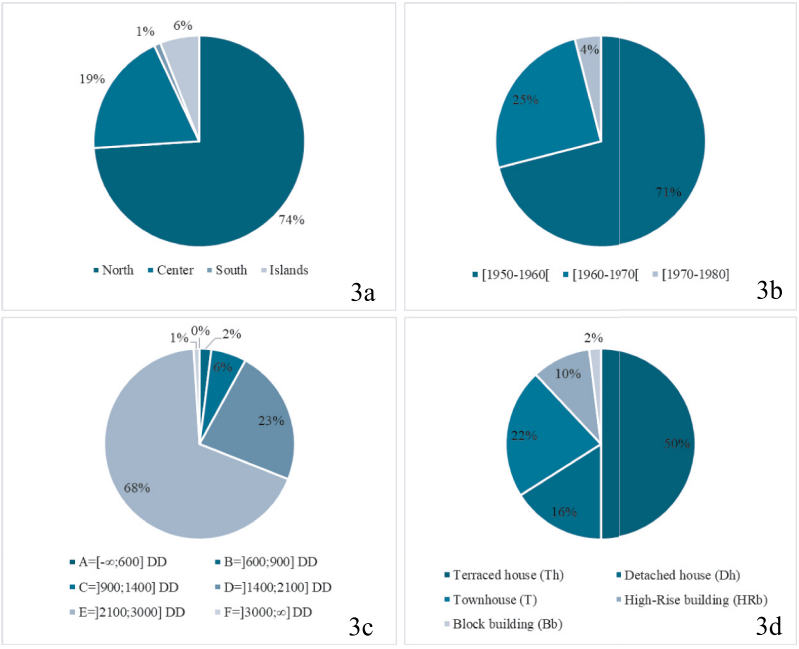


Fig. 3. Percentage distribution of the analyzed PRBs: 3a-Location; 3b-Construction period; 3c-Climatic Zone; 3d-Building Typology

were also identified (Table 3). A brief description and schematic representation of these sub-typologies are provided, along with their average data derived.

Figure 4 illustrates the percentage distribution of sub typologies for each building typology. For the Th typology, the linear configuration Th1 is predominant (68.18%). Among Dh buildings, the multi-family Dh1 is most common (81.74%), while for T buildings, the staggered single-family units T2 are prevalent (95.50%). The HRb typology, having no subcategory, naturally represents 100%. Lastly, among Bb typology, the linear configuration Bb1 is most common (60.78%).

Figure 5a shows the percentage distribution by typology of vertical structure (Vbs) across the entire sample of analyzed buildings, which reveals that 50.93% of the buildings under analysis have a Reinforced Concrete frame structure Vbs(RC).

This is followed by Load-bearing Masonry, Vbs(M), with 26.70%, and Prefabricated Concrete Vbs(PC) and Mixed structured Vbs(MA) with a percentage respectively around 12.19% and 10.17%. Figure 5b presents the percentage distribution of Vbs according to building typology. The typology "Terraced house (Th)", "High-Rise building (HRb)" and "Block building (Bb)" are predominantly built with Vbs(RC).

The Detached house (Dh) and Townhouse (T) typology, on the other hand, are mostly built with Vbs(M). These results are reliable, as Th, HRb and Bb buildings are generally much larger in size and higher compared to T and Dh and therefore require a structure with greater load-bearing capacity for vertical development. Conversely, T and Dh typologies have lower average heights, and thus load-bearing masonry is sufficient.

Table 2. Buildings'typology description (BT)

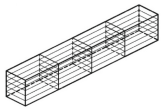
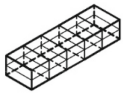
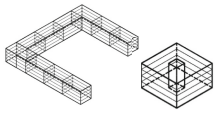
BT		DESCRIPTION	AXONOMETRIC REPRESENTATION
Th	Ter-raced house	Repetition (n-times) of a basic module, usually rectangular shape. The most common configuration is the "rectilinear" or in which the basic unit is arranged in succession, maintaining li ear and uniform elevations. On average, the building is compos of 4 basic units, total surface area of 1,120 m^2, 5 floors, volur of 21,140 m^3.	
Dh	De-tached house	Basic module, usually rectangular in shape, isolated from su rounding buildings. The multi-family typology is widespread. building with multiple floors, each with two residential units p floor. On average, the building has a total surface area of 230 n 2 floors, and a volume of 1,520 m^3.	
T	Town-house	It is composed of a basic unit, single-family, usually rectangul in shape, repeated n-times. Often in rectilinear succession. Ge erally, it is distributed on two levels. On average, the building made up of 5 basic units, total surface area of 450 m^2, has 2 floo and a volume of 2,970 m^3.	
HRb	High-Rise build-ing	It consists of a basic module, usually square in shape, isolat from the surrounding buildings. It is characterized by a notab height. On average, it is made up of 9 floors, total surface area 800 m^2, volume of 27,790 m^3, 4 housing units per floor.	
Bb	Block build-ing	It is characterized by the repetition (n-times) of a basic modu usually rectangular in shape. The basic unit is not placed in rec linear succession, but is repeated by configuring C-shapes, courtyard, Greek, or in general creating asymmetric configu tions. On average, the building is made up of 9 basic units, to surface area of 2,700 m^2, 4 floors, volume of 38,880 m^3.	

Table 3. PRBs' Sub-Typology (BsT) description and configuration

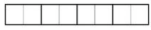
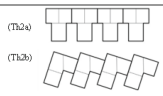
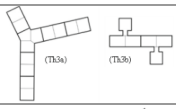
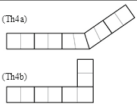
BT	BsT	Defini-tion	Description	Plan
Th	Th1	In line	Repetition (n-times) of a basic module, usually rectangular in shape. It is arranged in succes-sion, maintaining linear and uniform elevations.	
	Th2	Comb-shaped	The basic module, usually with a shape like Th2a or like Th2b, is arranged in succession, giving movement to the building's elevation by alternating full and empty spaces.	
	Th3	Multiple wings	The shape of the basic module is generally rec-tangular or square, with the exception of the connections. It can be "star" (Th3a), "T", "mir-rored T" (Th3b), etc.	
	Th4	Angled wing	The basic module, usually rectangular, is multi-plied n-times and arranged in succession by var-ying its planimetric inclination, which can be slight (Th4a), or greater up to 90°, leading to an "L" configuration of the building (Th4a).	

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Table 3. (*continued*)

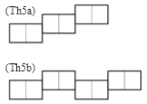
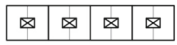
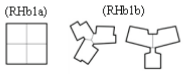
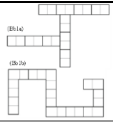
	Th5	Staggered blocks	The basic module, usually rectangular, is multiplied n-times and arranged in staggered succession, interrupting the linearity of the elevation. The units can be arranged with the same pattern (Th5a) or varying it (Th5a).	
	Th6	Inner courtyard	This typology of building is characterized by the central presence, in the basic module, of an empty space (e.g. patio or courtyard). The basic module can have a variety of shapes, usually square or rectangular.	
	Th7	Balcony access	This typology of building is characterized by the presence of external balconies for access to the housing units, located on the facade. The basic module can have a variety of shapes, usually square or rectangular.	
Dh	Dh1	Multi-family	The isolated building is composed of a basic module, usually rectangular in shape, isolated from the surrounding buildings. It is a multi-story building, each with two residential units per floor.	
	Dh2	Two-family	The basic module is generally rectangular in shape. Usually, the two residential units are distributed over two floors.	
	Dh3	Single-family	The basic module is generally square or rectangular in shape. The residential unit can be distributed over one floor (Dh3a), or over two (Dh3b).	
	Dh4	Multi-family Patio	The isolated "patio" building is characterized by the arrangement of the basic modules, generally rectangular or "L" shaped, so as to form a central patio.	
T	T1	In line Single-family	The terraced building is composed of a basic unit, single-family, usually rectangular in shape, repeated n times. The unit is placed in succession in a rectilinear way, generally the housing unit is placed on two floors	
	T2	Staggered Single-family	The basic unit, single-family, rectangular, repeated n times, is placed in succession in a staggered way. Generally, the housing unit is designed on two floors.	
HRb	HRb1	High-Rise building	A basic module, isolated from the surrounding buildings, is repeated vertically. Usually, the footprint is square in shape (RHb1a), but it can also take on a "star" configuration (RHb1b).	
Bb	Bb1	Linear	The generic block building is characterized by the repetition (n-times) of a basic module, usually rectangular in shape. The basic unit is repeated creating non-symmetrical configurations (e.g. Bb1a, Bb1b).	

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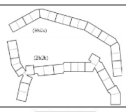
Table 3. (*continued*)

Bb2	Obtuse angles	The basic module, usually rectangular, is multiplied n-times and arranged in succession by varying its planimetric inclination and creating complex configurations.	
Bb3	Single court	The basic module, usually rectangular, is multiplied n-times and arranged in succession creating a central courtyard.	
Bb4	Linear court	The basic module, usually square, has a central courtyard. It is then arranged in linear succession.	
Bb5	Double court	The basic module, usually square, has a central empty space. Together with another unit, which can be of various shapes (square, rectangular, Z-shaped, L-shaped, etc.) it forms another courtyard with a larger size.	

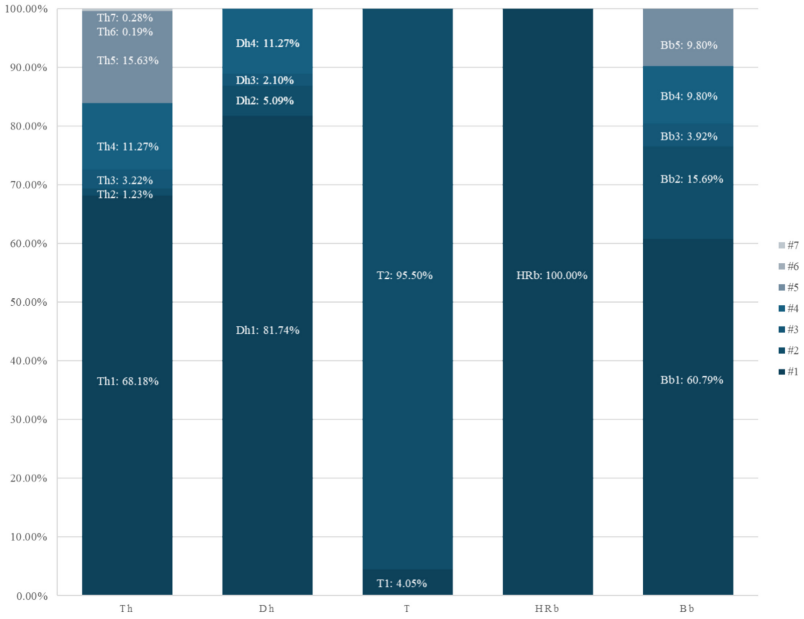


Fig. 4. Percentage distribution of the analyzed PRBs'Sub-Typology (BsT).

4.3 Structural Results

Regarding the Slab type (St), and particularly the Roof Type (Rt), four main categories have been identified (See Table A1), among which the reinforced Concrete and masonry structure prevails with 94.14% for the former category, as well as Concrete and masonry Roof (RtSM) at 64.71% and only 11.34% in wooden roofing (RtW) for the latter. As for the Roof finishing (Rf), four types have been identified (see table A1 in Annex), the prevalent ones are, with 60%, those in Clay Tiles (RfCT) and, unfortunately, there

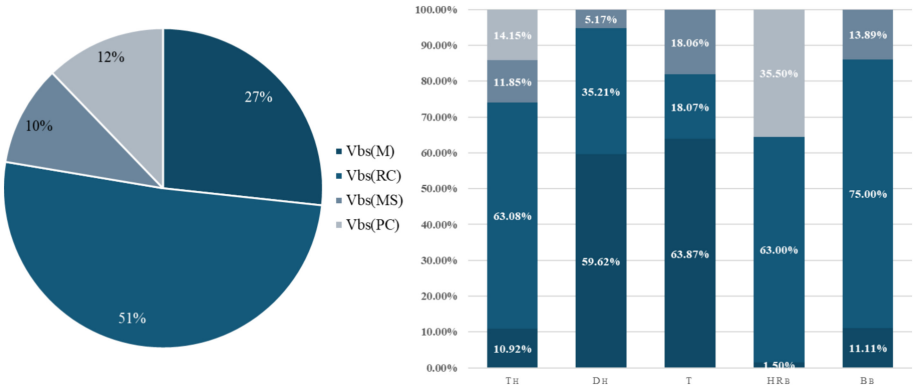


Fig. 5. Percentage distribution of the analyzed PRBs: 5a Vertical Building Structure (Vbs); 5b-Vbs by Typology.

are still many buildings (27.71%) that have asbestos as roof finishing (RfE). Regarding the windows and doors, information was obtained on material type (Wdt) and Shading Type (WDb). It emerges that the most used material for the frame of windows and doors is wood (59.81%), followed by aluminum (25.16%). As for Blinds, the most common types are wooden roller blinds (46.23%) and wooden shutters (34.68%).

4.4 TABULA Comparison

Finally, the last aim of Phase I of this research was to delve deeper into what was carried out by the "TABULA" project [9] regarding the classification of buildings according to their "Building Typology". As we previously mentioned, TABULA is a European project, which had the general objective of making energy renovation processes in the European housing sector transparent and effective, in line with energy policies. TABULA uses "MACRO-typologies", identified within a building stock as a starting point to evaluate energy renovation processes in order to guide stakeholders in their energy requalification projects, in terms of costs and effective energy savings. Compared to the TABULA project, this study focused solely on public residential stock and expanded the number of identified typologies (BT) from four to five. Climate zones (CZ) were considered without aggregation. Building Data (Bd) was collected through desk research, georeferencing, and estimated geometric data, either measured or provided by cadastral surveys, increasing from one variable in TABULA to 20 in this project. The concept of "Building Typology" from TABULA has been expanded, resulting in a more detailed classification. The Building Typologies (BT) identified here are primarily based on the typological layout and the building′s planimetric-volumetric configuration, considering factors such as surface area, height, surface-to-volume ratio, shape, aggregation methods, and more. These typologies enable the assessment of how the aggregation of individual residential

units influences the building′s energy performance. Further investigations were conducted on various parameters described by TABULA, including climatic, dimensional, and constructional data. To complete the study, it was deemed necessary to associate each building with its construction typology, including building materials, in relation to the building type, based on geographical area and data available in literature. Regarding the construction period, as previously mentioned, this study focused on a narrow range between the 1950s and 1980s, which represents the period of greatest development in public residential construction in Italy. Table 4 provides additional details concerning the differences between the two projects. This approach allows for a more comprehensive analysis of the building stock, taking into account the complex interplay between building typology, construction methods, and geographical context.

Table 4. Comparison between TABLUA's and the Current Stud's Variables

TABULA	OUR STUDY
Residential Buildings	**Public Residential Buildings**
Building Typology (BT)	
4: Single-family; Townhouse; Multifamily; Block building	5: TH; DH; T; HRb; Bb
Building Sub-Typology (BsT)	
No	Yes (total 19 Sub-Typologies)
Climatic Zone (CZ)	
3: E; F; and A-B-C-D	6: A; B; C; D; E; F
Building Data (Bd)	
1: Number of Units	20: LCA; BCA; ACA; P; DS; NS; NhS; BV; BldgV; NuB; NuBldg; NuF; Nr; Ur; Vbs; St; Rt; Rf; WDt; WDb
Building Structure Vertical Categories (Vbs)	
3: Masonry; Reinforced concrete; Other	4: Masonry (subcat. 1-8); Reinforced concrete (subcat. 1-10); Mixed structure (subcat. 1-4); Prefabricated Concrete (subcat. 1-5)
Construction Period (Yp)	
8 Classes: between 1900 and 2005 (20 yrs gap between the classes)	3 Classes: between 1950-1980 (10 yrs gap between the classes)

Extending the TABULA methodology, this study provided a deeper understanding of the physical, spatial and dimensional characteristics of PRBs in Italy, providing a starting Atlas to develop more targeted and effective energy efficiency retrofit strategies.

5 Conclusions

This research has made significant strides in classifying and analyzing the Italian PRB stock constructed between 1950–1980 during the INA-Casa program era. Through an extensive literature review and data collection process, a comprehensive database was created containing detailed information on 2,115 public residential buildings across Italy. The analysis identified five distinct building typologies terraced houses, detached houses, townhouses, high-rise buildings, and block buildings along with 19 sub-typologies based on their planimetric configurations and volumetric characteristics. Key parameters such as geometry, construction materials, energy systems, and climate zones were cataloged for each typology.

This refined typological classification advances previous efforts like TABULA by providing a more granular understanding tailored specifically to Italy′s public housing sector. While Phase I has successfully established this detailed database, it is limited by its focus on classification without yet addressing energy performance or retrofit strategies. The database serves as a robust foundation for the subsequent phases of this research. Phase II will build upon this typological framework by evaluating the energy performance of representative buildings from each identified typology. This will involve energy simulations and analyses to quantify current consumption patterns and identify areas for improvement. Phase III will then focus on developing and assessing cost-effective energy retrofit strategies tailored to each typology, considering technical, economic, and environmental factors.

Ultimately, the outcomes of this multi-phase project have the potential to inform policymakers in developing targeted incentive programs and policies to improve energy efficiency, mitigate climate change impacts, and alleviate energy poverty afflicting low-income households residing in these aging, energy-inefficient public residential buildings. By bridging the gap between generic classifications and the realities of Italy-′s public housing stock, this research represents a crucial step towards achieving national and international sustainability goals while enhancing the living conditions and well-being of vulnerable populations.

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APPENDIX

Table A1. Database variables acronym, description and unit of measure (**NC = Nominal Categorical, Co = Continuous, Du = Dummy, Di = Discrete)*

PARAMETERS	Description	Data type *	Unit of measurement
ID#	Building ID Number	Di	Progressive Number
DN#	District Name	NC	Name (Text)
Location			
IDl	Italian Geographical Area	NC	North (IDl1); Center (IDl2); South (IDl3); Islands (IDl4)
IDc	City	NC	Name (Text)
IDa	Building Address	Di	GCS
Construction Period			
Ys	Year of construction start	Di	Year
Ye	Year of construction end	Di	Year
Yp	Building construction period	Di	[1950-1960[; [1960-1970[; [1970-1980]
BU	Type of residential building	Du	Public (1); Private (0)
Dimension			
DCA	Gross covered area of the entire INA-Casa district	Co	m2
BCA	Gross covered area of the building	Co	m2
UCA	Gross covered area of the single unit	Co	m2
GLA	Total gross area of the single unit	Co	m2
P	Building Perimeter	Co	m
DS	Building dispersing surface. Sum of the surface of the external facades, the lower floor and the roof	Co	m2
SV	Dispersing Surface/Building Volume Ratio	Co	m2/m3
Stories			
NS	Number of floors above ground. Basement and semi-basement floors are excluded. The height above ground of the latter is considered in the volume calculation	Di	Number
RS	Number of residential units floors. Useful for identifying the presence of commercial floors or garages on the lower floors of the building	Di	Number
Volume			
DV	Gross volume of the entire INA-Casa district. Obtained by adding the BVs with the same DN#	Co	m3
BV	Gross Building Volume. Obtained by multiplying BCA by RS	Co	m3
Number of Units			
NuB	Total number of units in the entire INA-Casa district	Di	Number
NuBldg	Total number of units in the building, multiplying NuF by RS	Di	Number
NuF	Number of units per floor of the building	Di	Number
Typological			

(*continued*)

Table A1. (*continued*)

PS	The shape of the floor plan of the basic module of the building (if single-family) or of the building itself (if multifamily)	NC	Square (1); Rectangle (2); L-shape (3); T-shape (4); Clover (5); H/butterfly (6); Star (7); Hexagon (8); Z-shape (9); Cross (10)
Aggregation scheme			
BT	Spatial shape of the building. It derives from geometric considerations (e.g. surface/volume ratio, planimetric development, etc.) and aggregation (isolated or composed of multiple repeated basic units or modules)	NC	Th; Dh; T; RHb; Bb
BsT	Subcategory for each Building Typology (BT). Defined based on particular shapes of single or aggregate modules, such as the direction of aggregation and its angle	NC	Th1; Th2; Th3; Th4; Th5; Th6; Th7; Dh1; Dh2; Dh; Dh4; T1; T2; HRb1; Bb1; Bb2; Bb3; Bb4); Bb5
Stairwell Position			
Nr	Number of ramps that make up the access staircase to the building	Di	Number
Ur	Number of dwellings served by a single stairwell in the building	Di	Number
BM	Number of "basic units/modules" in the building	Di	Number
Building Structure			
Vbs	Type of structure of vertical load-bearing walls	NC	Masonry -Vbs(M); Reinforced concrete - Vbs(RC); Mixed structure - Vbs(MS); Prefabricated Concrete - Vbs(PC)
St	Type of structure of intermediate floors	NC	Concrete and masonry (StCM); Varese type (StV); Hollow-core concrete (StC); Other (StO)
Rt	Type of structure of the roof slab	NC	Wood (RtW); Concrete and masonry (RtSM); Other (RtO)
Rf	Finishing material of the building roof	NC	Clay Tiles (RfCT); Marseille Tiles (RfMT); Eternit (RfE); Concrete Squares (RfCS)
Windows and Doors			
WDt	Window frame material	NC	Wood (WDtW); Aluminum (WDtA); PVC (WDtP); Iron (WDtI); Generic Metal (WDtM); Steel (WDtS)
WDb	Window shading type	NC	Wooden roller shutters (WDbW); Roman shutters (WDbR); Plastic shutters (WDbP); Wooden board shutters (WDbWB); Generic roller shutters (WDbG); brise-soleil (WDbS)
Climatic			
CZ	Climate zone in which the building is located, according to Presidential Decree 26 August 1993 n.412 (Table A in Annex A, updated on 24.10.2018)	NC	A=[-∞;600]; B=]600;900]; C=]900;1400]; D=]1400;2100]; E=]2100;3000]
O	Orientation of the largest facade	NC	North-South (O1); Ovest-East (O2); NO-SE (O3); NE-SO (O4)

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