The Challenge of Archetypes Representativity for Wide Scale Building Investigation in Italy

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Abstract

The recent focus on new strategies towards the achievement of smart cities and energy community goals has required a massive use of urban scale tools for building energy modelling. The main aim is to support decision makers to address urban energy policies allowing the development of energy scenarios combining multiple actions. Despite some exceptions of simplified input datasets, urban scale simulation tools commonly require a large amount of input data to describe the building stock investigated, depending on the tool and the modelling purpose. Several literature studies explained the building stock modelling challenge, enhancing the current lack of complete databases describing the national building stock. The regional datasets of energy performance certificates are not fit for purpose and are often not available for research or statistical analysis. To tackle this issue, a hybrid approach combining different sources of information can be implemented; however, large quantities of data belonging to heterogeneous datasets must be updated, harmonized, integrated, potentially reducing the available data or reducing the accuracy. For these reasons, a possible way is the definition of archetype and prototype buildings, defined as ideal buildings described by sets of characteristics considered as representative of certain clusters of the building stock. However, a major challenge still must be solved: how is it possible to properly distribute archetype properties respecting the real presence of buildings within the considered location? In this work the last Italian population and housing census has been used to determine the distribution of building typologies according to the Italian building stock. Statistical analysis allowed for the clustering of the available information to deal with the lack of information for urban scale modelling tools, providing useful data for the representativity of available information within the national building stock. Future applications will apply the methodology to other case studies.

1. Introduction

The building and construction sector, which is responsible for 36% of global final energy consumption and 37% of energy-related CO_2 emissions in 2020 (GBC, 2021), holds a pivotal role in the global energy transition. To tackle the pressing issue of climate change, the World Energy Transition Outlook report by IRENA[1] emphasizes the urgent need for drastic reductions in global CO_2 emissions, aiming for net zero by 2050 to meet the 1.5 °C climate target. A significant portion, up to US 963 billion $/year, is earmarked for building interventions, focusing on boosting renewable energy usage and adopting energy-efficient technologies[1]. The European Union (EU) lead this commitment, allocating a quarter of its budget's financial resources to tackle climate change. With the European Green Deal, targeting climate neutrality by 2050, member states are urged to incorporate sustainability principles, cleaner construction practices, and a cleaner and less emissive building sector into decisions regarding energy-related policies and investments (EU, 2019).

Upgrading the current building stock to a zero-carbon-ready standard stands out as a critical priority in meeting the decarbonization goals set for the sector by 2030 and 2050. However, retrofitting the building stock to a zero-carbon-ready standard poses a tough challenge, given that a minimum of 40% of developed economies' building floor area

1 Available at https://irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook (Apr 23rd, 2024).

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predates modern energy-efficiency standards, including the Rio Conference of 1992 and the Kyoto protocol of 1997. Attaining this objective requires a robust annual deep renovation rate of over 2 %, spanning the period from the present to 2030 and beyond (Teres-Zubiaga et al., 2020). Given that the rates of building retrofits have not reached the set targets for many years, and that these rates need to speed up drastically, the switching from a single building renovation approach to a district scale perspective is the most effective, considering the potential connections among buildings and the achievable share of renewable energy sources. However, the need to shift from the idea of single buildings retrofit to that of entire districts requires the support of large amount of data on buildings' characteristics, HVAC properties, and user profiles to fully hold the retrofit needs and potentials. The conceptualization of urban-level strategies requires the creation of building archetypes to broaden the perspective beyond individual buildings and capture the prevailing building typologies for effective modelling (Carnieletto et al., 2021) and retrofit technologies definition. However, gathering information on large building stocks often relies on census data due to the limited availability of extensive datasets. Typically, this data is anonymized and does not go beyond a province or municipal scale nor provide detailed characteristics that may be useful for the purpose of the archetypes. Therefore, the development of comprehensive archetypes requires a combination of a diverse set of data obtained from various sources (Mata et al., 2014).

The use of census data is an essential approach for researching and developing applications in multiple areas concerning the built environment.

Census data can be used for extrapolating information regarding the frequency of building characteristics in terms of materials, geometry, end uses, etc. This approach is normally used to achieve a good characterization of building stocks without validating the dataset at single building scale, supporting the definition of important indicators for socioeconomic weaknesses. By integrating data gathered from surveys or local datasets, it is possible to better characterise groups of buildings or areas according to the intended goals of the analyses. For example, questionnaires are used to document the habits regarding the use of household appliances (Duman et al., 2023), energy consumption of decentralised sources (Marigo et al., 2021), or economic characteristics of households and how these affect their spending and well-being (Perchiunno et al., 2020).

Despite the wide application range of census data, the databases are often not easily accessible, if not even closed to consultation. This is the case for Italy. Various studies attempting to develop strategies for the energy renovation of the Italian building sector have faced countless difficulties in obtaining the necessary data due to this fragmentation of databases (Agugiaro, 2016). The use of data made available by the National Institute of Statistics (ISTAT) databases represents a necessary and fundamental solution to cope with the shortcomings. When it comes to the residential real estate sector, the quantities of data offered by ISTAT are useful for characterising buildings by age, construction type and building systems. Although not always fully representative, due to the lack of updates since 2011, the outcomes obtained represent a significant baseline for any work saving time-consuming analysis and for the development or national archetypes for urban scale energy simulations.

2. Method

In 2011 ISTAT released the 15th Census of the national population. Data was collected and grouped at municipal level, with algorithms able to check the reliability of each group of individual data, as described by the detection strategies (Carbonetti, 2023).

Since the main goal of this analysis is to statistically represent the national building stock to provide useful information for urban scale analysis and energy retrofit scenarios, the main outcomes concern a set of minimum information characterizing buildings in order to develop detailed archetypes to perform energy simulations. The geometric layout has been excluded from the analysis. In general, there is a lack of datasets regarding the geometrical layout of building footprints; when available, they can be uploaded from georeferenced tools.

Italy is divided in five different areas, as the location and the related historical development and cultural differences may influence the installed building technologies:

- North West: Piemonte, Liguria, Valle d'Aosta, Lombardia
- North East: Veneto, Trentino Alto Adige, Friuli - Venezia Giulia, Emilia Romagna
- Centre: Toscana, Umbria, Marche, Lazio,
- South: Campania, Calabria, Puglia, Basilicata, Abruzzo, Molise
- Islands: Sicilia and Sardegna

Nationwide, a total of 14,452,680 buildings were surveyed in 2011. The database can be divided in two main categories: residential and non-residential buildings. The work focused on the residential sector which represents the largest share of the surveyed buildings (around 12,187,698 constructions). The analysis is based on the 110 Italian provinces grouped by geographic area. Based on the defined pertinence area (from north to south), the average surface areas and user related variables, such as the typical occupancy ratio, have been discussed. Furthermore, buildings have been grouped according to the period of construction and to the main building technology adopted (bricks, concrete, or other materials). The last subsection describes the main energy sources for space heating and domestic hot water.

3. Results

The 12,187,698 residential buildings include about 31,208,161 housing units surveyed in 2011; 77.3% were occupied by at least one resident person, with the remaining 22.7% being vacant or occupied only by non-residents. Probably due to the intense presence of tourism and the related services, Valle d'Aosta had about 50.1% of homes unoccupied by residents, followed by Calabria (38.8%) and Molise and the province of Trento (37.1%). On the contrary, the province of Bolzano (88%), Lombardy (85%) and Campania (83%) has the highest ratio of units occupied by residents. The outcomes presented in the following paragraphs can be considered as distinctive features for the description of national archetypes, outlining some fundamental characteristics in terms of structural typology, generation systems, and usage type based on climatic zone, region, and year of construction. These results can be used to complement existing databases or serve as a framework for the construction of national archetypes.

3.1 Building Use

About 84.3% of the total buildings investigated belong to the residential sector (Table 1), among which 51.8% are single dwellings. The same trend can be seen at regional scale, excluding Valle d'Aosta (about 73.6%).

Table 1 – Building stock division based on end uses

	Italy	NW	NE	Centre	South	Island
N. blds [Millions]	14.4	3.32	2.78	2.44	3.63	2.32
Resid.	84.3%	83.9%	85.9%	83.8%	84.3%	83.6%
Product	2.0%	2.7%	2.6%	2.0%	1.3%	1.3%
Comm.	1.7%	1.8%	1.7%	1.8%	1.6%	1.4%
Tertiary	0.4%	0.5%	0.4%	0.4%	0.4%	0.4%
Tourism	0.4%	0.4%	0.5%	0.5%	0.4%	0.3%
Service	1.2%	1.4%	1.3%	1.3%	1.2%	1.0%
Other	4.8%	5.1%	4.1%	6.1%	4.0%	4.8%
Non defined	5.1%	4.2%	3.4%	3.9%	6.8%	7.2%

Figure 1 shows the share between non-residential buildings (16% at national scale), which include constructions for productive use (18.9%), followed by commercial (16.2%) and services (11.7%). The smallest share belongs to tourism/reception and office/tertiary use (about 4% each).

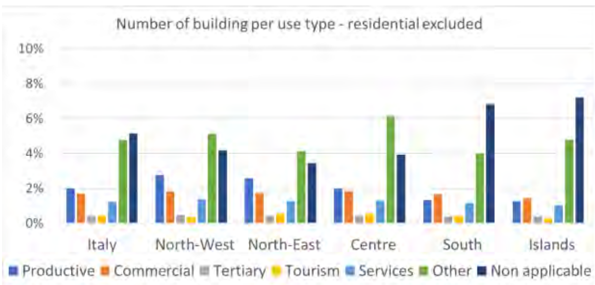

Fig. 1 – Building stock representation based on end uses (residential excluded)

3.2 Geometry and User Related Variables

Italy has a fairly even distribution of residential building types. Small (31%) and medium to large apartment blocks (40%) are the most frequent dwellings (Table 2). A significant difference can be seen within the northern regions: on the east side, the prevalent housing solution is the condominium with three to ten units (29%), while on the west side and central area almost half of the residential building are apartment blocks with more than 11 internal units. This trend can be linked to the massive industrial development after the world wars, which gathered groups of people to find employment (Salvati et al., 2017). Several districts of the bigger cities underwent urban development based on wide blocks intended for less affluent people and owned by the municipality or local authorities.

The southern area traces the same national share, while islands prefer small condominiums; the reason could be related to the highest building density in the main cities, while the countryside is mostly left for activities related to agriculture and animal farms. Single family houses are almost equally spread nationwide, with a slightly higher presence in the islands.

Table 2 – Residential building per number of internal units

Area	Number of units			
	1	2	3-10	>11
Italy	17%	13%	31%	40%
North West	17%	10%	25%	48%
North East	17%	16%	39%	29%
Centre	13%	12%	31%	44%
South	17%	13%	32%	39%
Islands	20%	17%	35%	28%

Looking at the average surface of dwellings (Table 3), similar shares can be distinguished. The interval of 80-99 m^2 is the most evenly distributed; this size is compatible with an apartment for a family of three or four people, which represents 14% (northwest) to 21% (centre) of the typical user occupancy (Table 4). The share of the smallest area is not representative; similarly, dwellings with more than six users have a share of less, except in the southern regions where it is 2.3%.

Although around 30% of the buildings in each area are inhabited either by one or two people, the smallest dwelling areas are less frequent.

The census investigated is the last complete database describing the national building stock but it dates back 2011, thus an updated version would probably present some differences. In the past 13 years, part of the buildings could have been retrofitted according to the retrofit targets imposed by standards promoting strict policies on energy efficiency. Furthermore, the average occupancy density of buildings per area may have changed due to the continuous evolution of the population. However, considering that the number of new buildings decreased (from 54,664 in 2018 to 49,100 in 2020[2]), the national renovation rate was about 0.85% per year until 2020[3], and the occupancy density profile will be attributed based on the area of interest in case of urban scale analysis, the information reported can still be considered as a baseline for the representation of the Italian stock when validating for example urban scale energy models.

Table 3 – Share of the residential building per dwelling area

Dwelling area [m^2]	Italy	NW	NE	Centre	South	Island
29	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
30-39	1.9%	2.1%	1.4%	2.0%	2.0%	1.9%
40-49	4.6%	5.6%	3.9%	4.8%	4.2%	4.2%
50-59	6.7%	8.2%	5.8%	7.1%	5.7%	5.6%
60-79	21%	24%	19%	22%	18%	17%
80-99	25%	25%	24%	25%	27%	24%
100-119	17%	15%	18%	17%	19%	21%
120-149	12%	10%	13%	11%	13%	15%
>150	11%	10%	15%	10%	11%	11%

2 https://www.istat.it/storage/ASI/2021/capitoli/C18.pdf (May 10th)

3 Ministero dello Sviluppo Economico (MISE), Strategia per la Riqualificazione energetica del parco immobiliare Nazionale, Nov. 2020

Table 4 – Share of the residential building per number of occupants

Number of users	Italy	NW	NE	Centre	South	Island
1	30%	32%	30%	31%	25%	28%
2	28%	30%	29%	28%	24%	25%
3	20%	20%	20%	21%	20%	20%
4	16%	14%	15%	15%	21%	19%
5	4.5%	3.2%	3.8%	4.0%	6.9%	5.4%
>6	1.6%	1.1%	1.6%	1.6%	2.3%	1.6%

3.3 Construction Technologies

The history of the Italian state significantly influences both the construction rate, and the technologies applied. A large fraction of the building stock belongs to the period before World War I (i.e., before 1918), with values ranging from 10.5% in the South to 14.6% in the Northwest of the country (Figure 2). The islands have the lowest share (about 5.7%). The decline visible between the two world wars is recovered in the period immediately following: 60-61% of the building stock was built between 1946 and 1990, in the North, about 64% in the central area, and 67 to 70% within southern Italy and Islands, respectively. This phase of high building intensity can be attributed to the historical period, corresponding to industrial development and the urgent need for building reconstruction. A consequence of this rather driven development, a downward trend began in the 1990s and ended with the financial crisis that occurred between 2008 and 2011, when the share of building constructions ranges on average between 4% and 3.5%. At regional scale, the behaviour can differ from the national trend. The most intense period in the north-west area (Piemonte and Lombardy) was the decade 1961-1970, driven by the emerging industrial and manufacturing growth. Veneto and Friuli Venezia Giulia on the east side has on average the same share until the 1980. Lombardy and Tuscany still have around half a million buildings belonging to the period before 1918. This building category is particularly relevant in Tuscany, which holds a high density of historic buildings preserved as cultural heritage that represents 20% of the regional stock. The lowest share of historic constructions is registered in Sardinia, with less than 5 %.

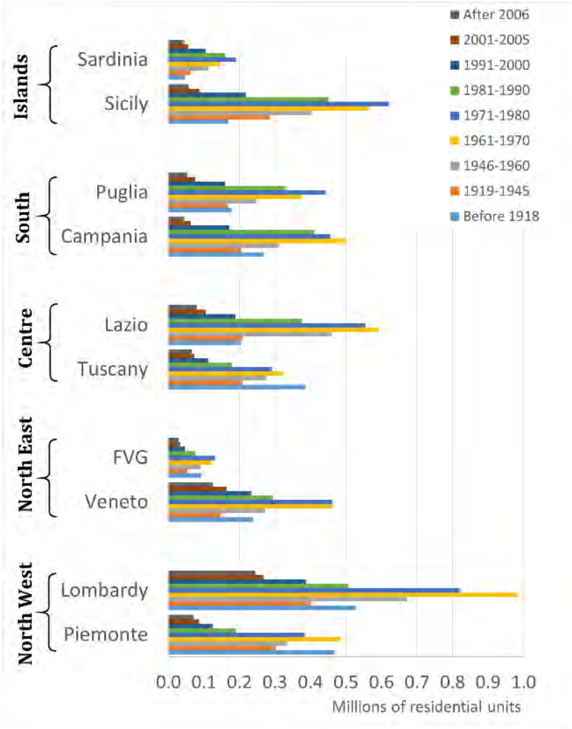

Fig. 2 – Number of residential buildings per period of construction

According to Figure (3 a-e) brick structures have been the most common construction technology until 1970 throughout the country. Later, the share of buildings material changed for each area, following the different growth of the industrial development. Since the early 1960s, concrete has become dominating over masonry construction in the north-west of the country (Figure 3a); a similar trend can be seen in the southern and central areas (Figures 3c, 3d, 3e), although from early 1970s. Within the north-eastern regions (Figure 3b), bricks and concrete have been used almost equally from 1980, with a significant and contemporary increase of other materials (mostly wood).

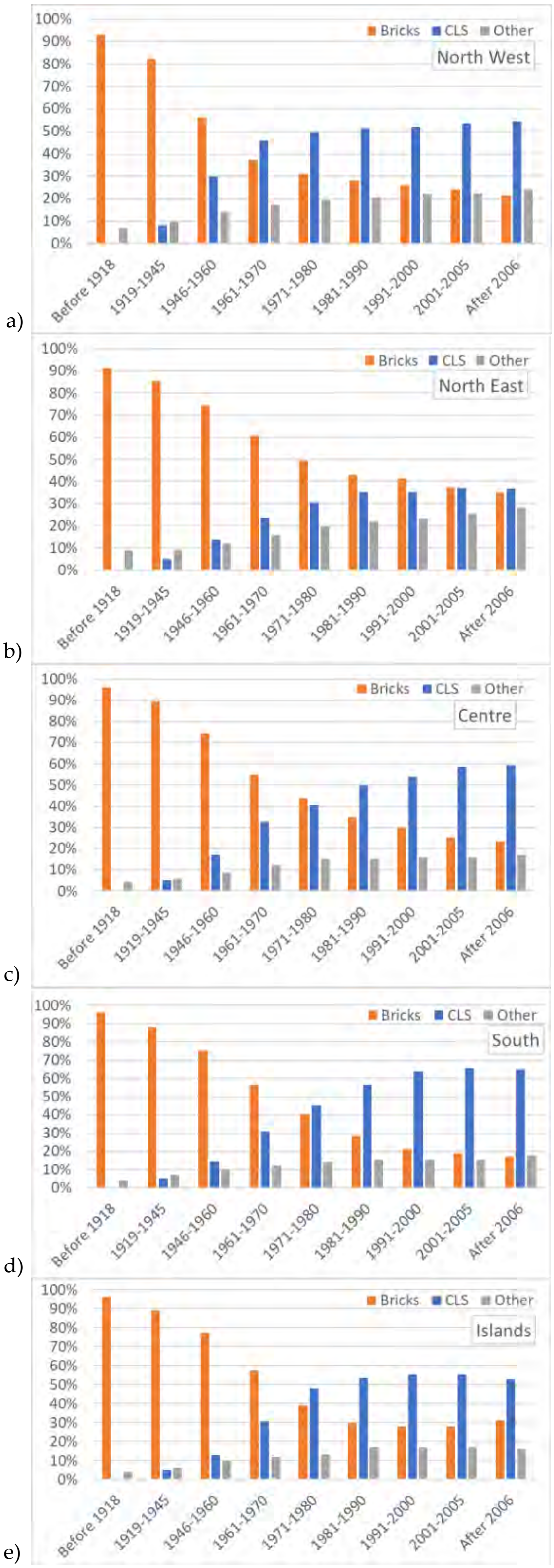

Fig. 3 – Building share per construction material and geographic area: North West (a), North East (b), Centre (c), South (d), Islands (e)

3.4 Energy Sources for Space Heating

Some information was collected concerning the energy source used for space heating. Natural gas is still the main source (Figure 4), supplying on average more than 70% of the buildings, as can be seen from the national statistics. Islands have a significantly lower share due to a less developed distribution grid. For the same reason, a notable fraction of diesel boilers and solid fuels, mostly wood, are still used for space heating.

On average electricity was supplying 5% of space heating systems; however, due to the lack of distributed natural gas pipelines, increased solar radiation and windy areas, electric energy is the heating source for 22% of the buildings in the two main islands (Sicily and Sardinia).

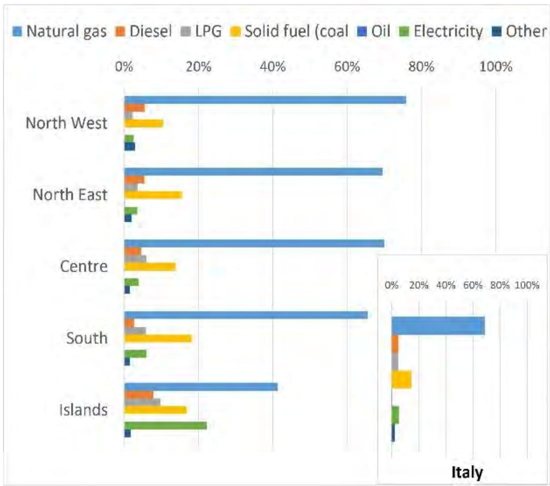

Fig. 4 – Distribution of energy sources for space heating

The same system is used for space heating and domestic hot water in about 69% of the dwellings in the country. When looking at smaller areas, this solution has been adopted in 85.6% of the buildings located in the north-east, 69.6% on the north-west and 74.2% in the central regions. Southern areas are closed to the national median (65.2%), while the Islands area covers only 35.5%, mostly due to the lack of methane pipelines, thus gas fired boilers. According to the report on the national energy system provided in 2023 by the national agency for new technologies, energy and sustainable economic development (ENEA, 2023), gas is still the most used fuel; although the demand in 2023 decreased by 2% compared to 2022, ENEA attributes the main reason to favourable climatic conditions. A decline was

estimated also for other commodities, in particular petroleum products and electricity from the grid.
The different distribution of generation systems depends also on the location and the related climate zone. The distribution of the climatic zones (from A to F, classified based on DPR 412 (1993) has been studied at municipal scale, thus grouped for the representation at regional scale. In figure 5, zone A is almost not represented since it is attributed only to two locations (Lampedusa and Porto Empedocle), thus the geographical representation is negligible. Zone F is typical of mountain areas; thus, it is present in the Alps and Apennines. Zone B can be found only in the South, while C and D commonly describe the coastal area. Climate zone E is the vastest area throughout the Italian peninsula.

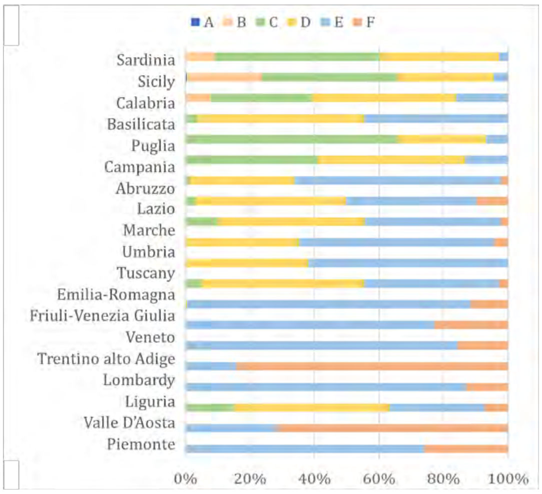

Fig. 5 – Climate zone distribution (municipality share per climate)

4. Discussion and Conclusion

The present work represents a first analysis of the building census provided by ISTAT in 2011, aiming to obtain a reliable statistic to be applied for urban scale energy simulations. Due to the lack of complete databases describing the national building stock, the outcomes obtained can complete other partial datasets, allowing the development of representative building archetypes for specific periods of construction and geographical areas. Within this framework, this paper provides a first description of the Italian building stock, mostly focused on residential dwellings that cover the majority of the buildings. In the last 13 years, the situation has partly changed due to the policies concerning energy savings and the improvement of energy efficiency. However, the renovation rate up to 2022 was about 0.85% per year; after that a massive incentive policy supporting refurbishment actions partly increased the renovation rate, which is still far from the goal (1.2%, with respect to a goal of 2.1%). Therefore, the resumed information can still be used as a valid statistic for a baseline validation of urban scale building energy models while updated information are not available. In fact, some input parameters used in a modelling or simulation process are defined by specific tools (like georeferenced tools that provide geometric data), while others are based on average values derived from standards or from randomized distributions. This means that instead of using precise local data for every input, the model relies on statistical averages that represent typical conditions for specific input categories. This approach helps to smooth out the effects of localized variations, ensuring that the simulation reflects broader trends rather than specific local conditions. Moreover, large scale models (i.e., wider than small district level) aim to represent the overall performance rather than the single building calibration. Furthermore, the outcomes obtained can be used for the calibration of national case studies. In conclusion, the methodology used and the variables investigated, based on statistical analysis, could serve as key indicators for defining national archetypes, highlighting essential characteristics such as structural typology, generation systems, and usage patterns according to climatic zones, regions, and construction years. These findings can enhance existing databases or provide a foundation for developing national archetypes. A realistic view of building performances allows the development of more tailored policies, thus more achievable goals, according to the regional outcomes. Future research will focus on collecting data at a more localized level (province or municipality), incorporating more research findings as they become available, and applying these outcomes to various case studies to assess their potential utility, such as studying the building stock distribution to design case specific energy strategies with policymakers or urban planners.

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