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Master Thesis

Residential Building Stock in Piemonte, Lazio e Sicilia – Developing a National Classification for Energy Modeling

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Abstract

The thesis starts from a critical use of existing regional technical maps to reconstruct the building stock of three Italian regions—Piedmont, Lazio and Sicily—in a way that is more useful for energy analysis. The original *uso* fields in these geo-databases are heterogeneous and not designed for load modelling, so they are checked, cleaned and harmonized into a common structure. On this basis, the work develops an energy-oriented hybrid classification that groups buildings into a small set of classes (RL, RM, PA, SP, TC, TH, TT, Others) and isolates the residential stock, with a specific distinction between purely residential buildings (RL) and mixed-use residential buildings (RM). In Piedmont, where volume information and explicit mixed-use labels are available, a True Residential Volume (TRV) is introduced by subtracting a representative ground-floor layer from RM buildings, in order to approximate the volume actually associated with domestic electricity contracts.

In a second step, the hybridized building database is linked to standard electricity statistics. Residential indicators are constructed by combining provincial residential electricity data for domestic low-voltage users from ARERA (year 2023) with population and household counts and with the residential volumes derived from the hybrid classification. Annual demand is normalized per household and per unit of residential volume (gross and TRV-based), and simple metrics are extracted from ARERA hourly profiles for selected provinces. Sectoral electricity balances from RAEE are compared with the distribution of building volume across residential, service, industrial and primary classes.

The results show clear differences between the three regions: a north–Center–south gradient in residential demand per household and in daily load shapes, higher volumetric intensities in metropolitan provinces, and a systematic gap between the small share of building volume occupied by service buildings and their large share of electricity use. Overall, the thesis demonstrates that careful reinterpretation of existing building maps, combined with a simple hybrid classification and the TRV concept, makes it possible to derive spatially explicit residential demand indicators that are consistent with national statistics and useful for local energy planning and REC-oriented analyses.

Acknowledgements

As my master's studies in Italy come to an end, I look back on these years as a time of both learning and growing up. This thesis concludes a journey that was not only academic but also deeply personal, a phase of my twenties marked by doubts, attempts, changes of direction and small acts of courage. It would not have been possible without the support of many people.

I would like to express my sincere gratitude to my supervisor, Prof. Guglielmina Mutani, for her guidance, patience and trust throughout this work and during my internship experience. Your comments pushed me to be more rigorous, to justify my choices and to see energy and buildings from different angles. Even when the thesis felt overwhelming, your feedback helped me move forward step by step.

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1. Introduction

The decarbonisation of the European energy system increasingly depends on how cities manage their building stocks. Buildings account for a large share of final energy use and related emissions, and much of this demand is concentrated in residential neighbourhoods. At the same time, new policy instruments such as Renewable Energy Communities (RECs) are shifting part of the transition to the local scale, where citizens, municipalities and small businesses share renewable generation and manage demand collectively.

Within this context, Italian regions are investing in detailed geographic databases of buildings and in regional energy plans. Yet, linking these spatial datasets with aggregated electricity statistics remains challenging. This thesis contributes to this effort by proposing and testing a hybrid, energy-oriented classification of the building stock in three Italian regions—Piedmont, Lazio and Sicily—and by using it to construct simple, yet informative indicators of residential electricity demand at provincial scale.

1.1 Urban Energy Transition and the Role of the Residential Building Stock

European climate and energy packages emphasise the central role of buildings in reaching greenhouse-gas reduction targets and improving energy efficiency. Directives on energy performance in buildings and on renewable energy set increasingly strict requirements for renovation rates, electrification and on-site renewable generation. National recovery plans further reinforce these priorities, often framing buildings as both an infrastructure for decarbonisation and a lever for social policies such as the reduction of energy poverty.

Within the building sector, the residential stock is particularly relevant. Dwellings represent a large share of floor area in most European cities, and household electricity demand is directly affected by everyday practices, occupancy patterns and appliance ownership. In Italy, the residential stock is also highly heterogeneous: historic centres, post-war apartment blocks, detached houses and tourism-oriented dwellings coexist within the same regions. This diversity shapes not only annual energy consumption, but also the timing and intensity of demand, which are crucial for the design of RECs and for assessing the interaction between demand and distributed generation.

Understanding how this heterogeneous stock is distributed across space, and how it relates to observed electricity demand, therefore becomes a key step for urban energy planning. Geographical information systems (GIS) and regional technical maps already provide detailed building geometries and basic “uso” (use) labels, but these data need to be translated into classifications that are meaningful for energy analysis and compatible with available demand statistics.

1.2 Research Problem

Regional technical maps and electricity statistics are both well developed in Italy, but they rarely meet in a coherent framework. Building datasets describe geometry and “use” at the scale of individual footprints, while electricity data are reported at provincial or regional level and aggregated into broad sectors. As a result, it is still difficult to answer basic questions such as where residential electricity demand is concentrated, how it relates to the physical volume of the residential stock, and how mixed-use buildings in dense urban cores should be treated.

Three related gaps motivate this thesis.
First, building-use information in regional technical maps is heterogeneous and not explicitly designed for energy analysis. The same activities are labelled differently across regions, mixed uses are often implicit, and traditional sectoral schemes such as the R/P/S/T split are too coarse to distinguish between purely residential, mixed residential–commercial and tourism-oriented buildings.
Second, provincial electricity statistics for domestic users, as published by ARERA, are expressed per contract and per province, with no direct link to the underlying building stock. There is no straightforward way to see how observed residential demand corresponds to the number, type and volume of residential buildings in each area.
Third, mixed-use residential buildings are poorly represented in current indicators. Ground floors in Italian cities often host shops or services, while upper floors are residential, yet building databases usually report a single main use and volumetric indicators tend to count the entire volume as “residential”. This is only loosely

consistent with the legal distinction between domestic and non-domestic contracts and likely underestimates load intensity in dense, mixed-use neighbourhoods.

The thesis addresses these problems by proposing a simple, energy-oriented hybrid classification of the building stock for three regions—Piedmont, Lazio and Sicily—and by combining it with provincial residential electricity data. The underlying aim is to move beyond uniform sectoral averages and to provide a transparent, spatially explicit reading of residential demand that can support local energy planning and early-stage REC discussions, without requiring complex models or proprietary datasets.

1.3 Research Questions

Within this problem setting, the work is guided by three main research questions:

- **RQ1 – Hybrid classification and residential stock.**
  How does the proposed hybrid classification, and in particular the distinction between purely residential (RL) and mixed-use residential (RM) buildings, change the description of the residential building stock in Piedmont, Lazio and Sicily compared with a single undifferentiated residential category?

- **RQ2 – True Residential Volume and volumetric intensity.**
  In Piedmont, how does replacing gross residential volume with True Residential Volume (TRV) affect provincial indicators of residential electricity demand per unit of volume, especially in provinces with dense mixed-use urban cores?

- **RQ3 – Residential indicators and sectoral context.**
  How do provincial residential demand indicators per household, per unit of volume and from simple load-curve metrics relate to the underlying building-stock composition and to differences in overall sectoral electricity demand across the three regions?

The rest of the thesis responds to these questions by constructing a harmonised building-stock database, applying the hybrid classification, defining TRV where data allow it, and combining these elements with ARERA and RAEE statistics at provincial and regional scale.

1.4 Scope & delimitations

The study is limited in several ways that should be kept in mind when interpreting the results.

- **Spatial scope.** The analysis focuses on three regions—Piedmont, Lazio and Sicily—which form a north–centre–south transect of Italy and capture a wide range of climatic and urban–rural conditions. Within each region, all provinces are included, but detailed mapping is shown only for selected metropolitan areas. The hybrid classification is designed to be extendable to other regions, but this extension is beyond the scope of the thesis.

- **Unit of analysis.** Buildings are classified at footprint level, but most demand indicators are computed at provincial scale, reflecting the spatial resolution of ARERA's residential load data. Municipal and neighbourhood patterns are discussed qualitatively through maps rather than through separate quantitative indicators.

- **Temporal scope.** The main reference period is the most recent year for which provincial residential electricity data are available in a consistent format. Seasonal and weekday–weekend differences are captured by ARERA's monthly and daily-type curves, but long-term trends and future scenarios are not modelled.

- **Thematic focus.** The thesis concentrates on electricity demand in the residential sector and on the relationship between this demand and the building stock. Non-residential classes (services, industry, agriculture and tourism-related uses) are mapped and used to frame sectoral electricity balances, but they are not modelled in detail. Photovoltaic generation, REC performance indicators and economic evaluations are discussed qualitatively and remain outside the quantitative core of the work.

These delimitations reflect both data availability and the intention to keep the framework simple and transparent. They also point to directions for future extensions, such as applying the hybrid classification to other regions or integrating additional end-uses and technologies.

1.5 Thesis structure

The thesis is organised into seven chapters.

Chapter 1 introduces the policy and planning context, formulates the research problem, and sets out the aim, objectives, research questions and scope.

Chapter 2 reviews the relevant literature on RECs, GIS-based urban energy planning, building-stock classification and residential load modelling. It highlights the need for hybrid, behaviourally informed typologies and summarises the specific gaps that motivate the thesis.

Chapter 3 presents the methodological framework. It describes the GIS-based workflow used to harmonise regional building datasets, defines the hybrid classification and the treatment of mixed-use residential buildings, explains how True Residential Volume and provincial demand indicators are constructed, and outlines the curve-based metrics used to characterise residential load profiles.

Chapter 4 introduces the three study regions and the main data sources. It summarises the geographical and socio-economic context of Piedmont, Lazio and Sicily, and details the building, demographic and electricity datasets that support the analysis, including their spatial and temporal resolution and key limitations.

Chapter 5 reports the empirical results. It maps the spatial distribution of the hybrid classes, quantifies the composition of the residential building stock and the TRV correction, and presents provincial residential demand indicators per household and per unit of volume. It then relates these indicators to simple hourly-profile metrics and to regional sectoral electricity balances.

Chapter 6 discusses the findings in relation to the literature and to the research questions. It reflects on the strengths and limitations of the proposed hybrid classification, the robustness of the indicators, and the implications for understanding residential demand in heterogeneous urban contexts.

Chapter 7 concludes the thesis by summarising the main contributions, outlining practical takeaways for planners and policymakers, and suggesting directions for future work on extending and applying the classification at national scale.

2. Literature Review

This chapter reviews three strands of literature that frame the thesis:

(i) renewable energy communities (RECs) in the European and Italian context;

(ii) GIS-based urban energy modelling and REC planning; and

(iii) building-stock classification and residential load modelling.

Together, these strands point to a gap between high-level REC assessment tools and the coarse building-use data that are typically available at national scale. The thesis addresses this gap by proposing a simple, energy-oriented hybrid classification of the Italian building stock, focused on residential buildings and on their role in REC-type analyses.

2.1 Renewable Energy Communities in the European and Italian Context

Renewable Energy Communities (RECs) are promoted in the EU as a way to move from a centralized, utility-led system towards decentralized, citizen-driven energy governance. Directive (EU) 2018/2001 (RED II) formally defines RECs as legal entities based on open and voluntary participation, controlled by local members (citizens, SMEs or local authorities) and pursuing environmental, economic or social benefits rather than profit maximisation (European Parliament and Council, 2018, Art. 2(16)). Member States are required to set up an "enabling framework" that removes unjustified barriers, ensures non-discriminatory access to markets and support schemes, and protects REC participants (European Parliament and Council, 2018, Art. 22). RED II also recognises the rights of "renewable self-consumers" to generate, consume, store and sell electricity, either individually or through joint schemes (European Parliament and Council, 2018, Art. 21).

Directive (EU) 2023/2413 (RED III) reinforces this framework by simplifying permitting for renewable projects, including small-scale PV typical of REC initiatives, and by promoting on-site generation and self-consumption in buildings (European Parliament and Council, 2023, Art. 15a, 16d). It explicitly links RECs and self-consumption to energy poverty mitigation and to the integration of distributed resources, storage and electric vehicles as flexibility providers (European Parliament and Council, 2023, Art. 20a). In this sense, RECs are not only a new ownership model, but also a policy instrument for a more resilient and inclusive energy system.

In Italy, the REC framework has been implemented through a sequence of decrees and guidelines, culminating in the Ministerial Decree n. 414/2023 issued by MASE (Italian Ministry of Ecological Transition / MASE, 2023). Italian RECs must operate within the perimeter of a single primary substation (cabina primaria), which constrains the geographical extent of eligible members and anchors projects to specific grid areas (MASE, 2023, Art. 3). The National Recovery and Resilience Plan (PNRR) allocates dedicated funds to RECs in municipalities with fewer than 5 000 inhabitants, explicitly linking RECs to social cohesion and energy equity objectives (Ministry of Economic Development and Ecological Transformation, 2023).

From a technical point of view, REC performance is usually evaluated through indicators such as the Self-Consumption Index (SCI) and Self-Sufficiency Index (SSI), as well as broader “Objective Performance Indices” tailored to local economic or environmental goals (Bianco et al., 2021; Mutani & Todeschi, 2021; Long et al., 2021; Vecchi et al., 2024). These indices require time-resolved demand and generation profiles at community scale. Recent Italian and European studies highlight that realistic REC simulations are highly sensitive to the assumed hourly load curves of residential and non-residential users, and to the mix of building types included in the community (Lopez et al., 2021; Parra et al., 2017; Leprince et al., 2023; Mutani et al., 2024).

The rapid growth of small PV installations in Italy, documented in recent GSE statistical reports, confirms that a large fraction of new capacity is associated with households and small prosumers, consistent with the REC concept (GSE, 2024a; GSE, 2024b). However, much of the existing REC literature still works with simplified building categories or with synthetic “average users”, which makes it difficult to link REC scenarios back to the real building stock in specific regions. This motivates the need for building-oriented indicators that reflect how residential demand is distributed across different building forms and mixed-use configurations, as explored in this thesis.

2.2 GIS approaches in energy community planning

Geographical Information Systems (GIS) and urban building energy models (UBEM) have become central tools for analysing the spatial dimension of energy use in cities and regions (Reinhart & Davila, 2016; Poggi & Amado, 2024; Sola et al., 2018). By combining building footprints, land-use or cadastral attributes, elevation models, EPC data and socio-economic indicators, GIS-based approaches can map and model energy demand at multiple scales, from individual districts to entire metropolitan regions (Massimo et al., 2014; Mutani et al., 2023; Johari et al., 2023).

Resch et al. (2014) and Sola et al. (2018) underline that GIS is particularly powerful when used as a common platform for integrating heterogeneous datasets and for visualising the outcomes of energy scenarios in a spatially explicit way. Recent applications extend this logic to the siting of renewable technologies and to the identification of suitable areas for PV deployment, using multi-criteria or multi-influencing-factor methods (Mancini & Nastasi, 2020; Rane et al., 2024; Huang et al., 2022). These works show how solar potential, land-use constraints and infrastructure can be jointly assessed in a GIS environment.

For REC planning, GIS supports three main tasks. First, it maps the building stock and its uses within the electrical boundaries relevant for RECs (e.g. the cabina primaria perimeter), helping to identify candidate members and anchor loads (Mutani et al., 2024). Second, it provides spatial proxies for demand, by aggregating sectoral consumption data (e.g. ARERA and Terna statistics) over municipalities or neighbourhoods and correlating them with demographic or socio-economic variables (Mutani et al., 2024; Italian National Agency for New Technologies, Energy and Sustainable Economic Development, 2024). Third, it serves as a platform to test technology mixes and community configurations, linking hourly demand profiles with PV production, storage and control strategies (Saretta et al., 2021; Saltamerenda et al., 2024).

The Italian geoportal for RECs described by Mutani et al. (2024) is an example of such an integrated approach: it combines ARERA, Terna, ISTAT, GSE and regional datasets into a multi-scale GIS framework, allowing users to explore energy indicators at municipal, provincial and regional levels. At the same time, this work also exposes the practical difficulties of harmonising data from different sources and regions, especially when building-use definitions and spatial resolutions are inconsistent (Resch et al., 2014; ENEA, 2024).

This thesis follows the same GIS-based philosophy but focuses on a narrower objective: building a harmonised, region-wide database of residential buildings for Piedmont, Lazio and Sicily, and deriving simple volumetric indicators that can be linked to ARERA residential statistics. Rather than developing a full REC optimisation tool or a detailed UBEM, the work concentrates on the intermediate layer: a hybrid classification and a set of building-oriented metrics that can inform REC scenario analysis.

2.3 Building Classification Systems for Urban Energy Modelling

A large body of research has explored how to classify buildings for energy analysis and how to derive representative load profiles for different user groups. Traditional building-stock models often rely on typologies defined by construction period, geometry and use, sometimes complemented by EPC data or archetype libraries (Reinhart & Davila, 2016; Sola et al., 2018; Saltamerenda et al., 2024). More recent work has moved towards spatio-temporal typologies that explicitly link building attributes, location and usage patterns to energy behaviour (Sark et al., 2023; Johari et al., 2023; Mutani et al., 2023).

A recurring issue in this literature is data granularity. Kontokosta and Tull (2017) show that coarse, aggregated benchmarks can mask large variations between buildings and limit the usefulness of benchmarking tools. Similar concerns are raised in UBEM reviews, which note that the choice of typology and the resolution of input data strongly affect model outputs and their suitability for planning decisions (Reinhart & Davila, 2016; Sola et al., 2018; Poggi & Amado, 2024). For Italy, Mutani et al. (2023) demonstrate that combining EPC datasets with GIS-based building inventories can improve the statistical modelling of residential demand, but also highlight the effort required to clean and align regional data sources.

Residential load modelling itself has evolved from simple static profiles to more detailed, behaviour-based approaches. Classic work such as Taylor et al. (2008) and NREL’s GridLAB-D and ComStock initiatives model end-uses and thermostat behaviours to generate synthetic hourly profiles for large building stocks (NREL, 2021; NREL, n.d.-a; NREL, n.d.-b). Recent studies use occupancy-driven or machine-learning approaches to predict hourly consumption in individual buildings (Lopez et al., 2021) or to optimise energy communities under behavioural uncertainty (Leprince et al., 2023). These methods, however, typically require rich input data that are not available nationwide.

In mixed-use buildings, the challenge is not only to model behaviour but also to assign the correct portion of the built volume to residential versus non-residential demand. Lee et al. (2018) and other studies on mixed-use typologies show that the surrounding urban fabric and ground-floor uses can significantly affect building energy use. In Italy, the regulatory distinction between "clienti domestici" and "altri usi" in low-voltage tariffs implies that ground-floor commercial spaces and common services in condominiums are usually supplied under non-domestic contracts, even when they share a building with dwellings (ARERA; Sinergy Luce e Gas; Luce-gas.it; Sorgenia). This distinction is rarely reflected in technical maps or cadastral datasets, where buildings are often tagged with generic "residential" labels.

Against this background, the hybrid classification developed in this thesis adopts a pragmatic, GIS-ready approach. Instead of building a complex behavioural model, it introduces two residential classes: RL, for purely residential buildings, and RM, for mixed-use buildings where residential units coexist with non-residential activities. For RM buildings, a simple True Residential Volume (TRV) indicator is defined by subtracting a typical ground-floor storey from the total building volume, under the assumption that ground floors mainly host non-residential uses and are supplied under non-domestic contracts.

This approach has three implications. First, it aligns building-level indicators with how ARERA and suppliers actually define residential electricity contracts, making volumetric normalisation of ARERA statistics more consistent. Second, it acknowledges the importance of mixed-use morphology for load distribution, without requiring detailed tenant-level data. Third, it provides a compact typology (RL/RM) that can be mapped across large regions and used as an input layer for REC-type analyses, rather than as a full UBEM in itself.

In summary, existing literature offers many sophisticated tools for REC assessment and urban energy modelling, but it also illustrates the limitations imposed by coarse building-use categories and heterogeneous data sources. The thesis builds on these insights by proposing a hybrid, energy-oriented classification for the Italian residential stock and by testing its usefulness through regional-scale volumetric and load indicators in Piedmont, Lazio and Sicily.

2.4 Behavioural Load Modelling and ARERA Profiles

Residential electricity demand is not determined by building geometry alone. Occupant behaviour and appliance use strongly affect both total consumption and the shape of hourly load curves (Fabi et al., 2017; Delzendeh et al., 2017). Studies based on smart-meter data and surveys repeatedly show that households with similar dwellings can have very different demand patterns, depending on occupancy schedules, comfort preferences, and the use of specific appliances such as electric heating, air conditioning or electric vehicles (Pellegrino et al., 2023; Yan et al., 2017).

In Italy, ARERA provides provincial load profiles for domestic low-voltage customers, aggregated by contractual power class. These profiles summarise the typical daily and seasonal behaviour of residential users and are widely used as inputs in distribution-network studies and in REC simulations (Parra et al., 2017; Lopez et al., 2021). Their main advantage is that they are based on real metering data and cover the whole country. Their main limitation is that they are aggregated: all households in a province and power class are represented by a single curve, with no direct link to particular neighbourhoods or building types.

Contractual power classes can still be read as a coarse proxy for behavioural and technological differences. Higher contractual power is associated with a higher probability of electric heating, cooling or electric vehicle charging, and with larger peak loads (NREL, 2021; Glazar et al., 2023). Several REC and community-energy studies exploit this idea by assigning different ARERA profiles or synthetic variants to “low-demand” and “high-demand” households, rather than using a single residential curve (Lopez et al., 2021; Leprince et al., 2023; Vecchi et al., 2024).

This thesis follows a similar intuition, but at a more modest level. Instead of building a full behavioural model, it uses ARERA provincial profiles as given and focuses on how they are normalised: per household and per unit of residential volume, including True Residential Volume (TRV) in mixed-use contexts. In this way, behavioural differences are not modelled explicitly, but they are partly reflected in the indicators through the combination of ARERA data and the spatial distribution of RL and RM buildings.

2.5 Spatial–Behavioural Energy Typologies and Hybrid Classifications

Recent work in urban energy modelling argues that building typologies should reflect not only physical attributes and construction periods, but also typical operating hours and usage patterns (Reinhart & Davila, 2016; Sola et al., 2018; Sark et al., 2023). In practice, this means combining spatial information—location, surrounding land use, urban form—with simple behavioural descriptors such as daytime operation, evening-oriented use or 24/7 activity (Poggi & Amado, 2024; Lee et al., 2018).

For residential buildings, this distinction often boils down to a few robust patterns: primary homes with pronounced evening peaks, second homes and tourism dwellings with seasonal peaks, and mixed-use buildings where residential and non-residential activities share the same envelope but follow different schedules (Parra et al., 2017; Saltamerenda et al., 2024). Several UBEMs and REC studies therefore adopt hybrid classifications where function, operating hours and indicative demand levels are combined into a single label (NREL, 2021; Lopez et al., 2021; Vecchi et al., 2024).

The hybrid classification introduced in this thesis is aligned with this line of work but remains deliberately simple and GIS-friendly. It groups buildings into a small set of classes that carry both a sectoral meaning (residential, primary, secondary, tertiary) and an indicative demand intensity, while staying compatible with the R/P/S/T categories used in Italian statistics. Within the residential sector, the RL/RM distinction is explicitly motivated by mixed-use morphology and by the contractual separation between domestic and non-domestic electricity uses in Italian regulation (ARERA; Sinergy Luce e Gas; Luce-gas.it; Sorgenia). The detailed construction of the hybrid classification and its implementation are described in Chapter 3; here the key point is that such a typology allows building maps and provincial electricity statistics to be read through a common, energy-oriented lens.

2.6 Data Granularity, Harmonisation and Research Gap

The effectiveness of any building classification depends heavily on the quality and granularity of the underlying data. Reviews of UBEM applications highlight recurring problems: incomplete or inconsistent cadastral records, heterogeneous regional standards, and limited availability of reliable information on building use, height and age (Sola et al., 2018; Reinhart & Davila, 2016; Poggi & Amado, 2024). For Italy, recent work confirms that even well-established datasets such as EPC registers or regional technical maps require substantial cleaning and correction before they can be used for energy analysis (Mutani et al., 2023; D'Amico et al., 2020).

ENEA's Rapporto Annuale sull'Efficienza Energetica and the updated National Energy and Climate Plan emphasise the importance of robust data for building renovation strategies and for local energy planning, but they also acknowledge significant gaps in coverage and harmonisation across regions (ENEA, 2024; European Commission, 2024). EPC datasets are affected by sampling bias and variable quality; regional maps do not always distinguish mixed-use buildings; and sectoral electricity statistics provide little guidance on how to allocate demand to specific building types (Sola et al., 2018; Mutani et al., 2023; Vecchi et al., 2024).

These limitations have direct consequences. Coarse or inconsistent building data can lead to archetypes that misrepresent real stocks, to demand estimates that hide local heterogeneity, and to REC designs that are calibrated on unrealistic load distributions (Kontokosta & Tull, 2017; D'Amico et al., 2020; Leprince et al., 2023). The literature broadly agrees that more granular and harmonised building information would improve both UBEM and REC modelling, but concrete, region-wide examples that work with the data that are actually available remain relatively rare (Hong & Yan, 2019; Mutani et al., 2024).

This thesis positions itself in this gap. Rather than proposing a new national database or a highly detailed archetype library, it tests how far one can go by carefully reinterpreting existing regional technical maps, harmonising their uso fields into a hybrid classification, and linking them to provincial electricity statistics. The focus on

Piedmont, Lazio and Sicily reflects both data availability and the desire to cover a north–centre–south transect of Italy. The hybrid classification, the True Residential Volume concept and the residential indicators developed in the following chapters are intended as practical tools that sit between coarse sectoral averages and complex bottom-up models, and that can be reused or extended in other regional contexts.

3. Methodology

3.1 Methodological Framework for Building Stock Classification

3.1.1 Overview and objectives

This chapter sets out the methodological framework used to build and test a hybrid classification of the Italian building stock and to link it with residential electricity demand and sectoral electricity statistics. The approach is motivated by the limitations of existing sectoral schemes and regional technical maps, which provide detailed geometries and uso fields but lack a consistent, energy-oriented typology across regions. At the same time, electricity statistics are mostly available at aggregated scales and for broad sectors, which constrains their direct use in spatially explicit models.

The framework developed in this thesis responds to these constraints by combining semantic information on building use with regional and provincial energy data within a GIS environment. The main objectives are to:

- harmonise heterogeneous regional building datasets into a single geo-database suitable for energy analysis.
- define a hybrid, use-based classification that captures both functional sector and indicative demand intensity, while remaining compatible with the traditional R/P/S/T split.

- treat mixed-use residential buildings explicitly and derive a True Residential Volume (TRV) that is more consistent with ARERA's definition of domestic electricity contracts.
- construct provincial residential demand and intensity indicators by combining ARERA hourly profiles with residential volume metrics (gross and TRV-based);
- compare sectoral electricity consumption from RAEE statistics with the distribution of building volume across primary, secondary, tertiary and residential uses.

The emphasis is on residential buildings, where hourly demand information is more readily available and where REC policies are currently most active. Non-residential classes are still mapped and analysed, but they play a supporting role in this thesis: they provide the wider context of the built environment, help interpret sectoral electricity statistics and highlight high-intensity non-residential uses that could act as anchor loads in future REC-oriented applications.

3.1.2 Research design

The research design follows a GIS-based workflow that links data preparation, building classification and the construction of residential demand indicators. All datasets introduced in Chapter 4 are first assembled into a common spatial framework. Regional building technical maps for Piedmont, Lazio and Sicily are cleaned, reprojected and enriched with height or volume proxies and basic morphological indicators. These spatial layers are integrated with non-geometrical information, including provincial hourly electricity demand, annual sectoral energy statistics, and population and household data, to form a unified geo-database.

On this basis, the methodology proceeds in four main steps:

1. **Hybrid classification of the building stock.**
   The original uso attributes in the regional maps are translated into a set of hybrid energy-oriented classes (RL, RM, PA, SP, TC, TH, TT and Others) through region-specific dictionaries. This step produces three harmonised,

hybrid-classified building stocks that are comparable across regions and compatible with the R/P/S/T framework used in Italian statistics.

2. **Treatment of mixed-use residential buildings and TRV.**
   Mixed-use residential blocks (RM) are identified and processed to distinguish the residential and non-residential portions of their volume. In Piedmont, where additional volume and height information is available, a True Residential Volume is computed by subtracting a representative ground-floor volume associated with non-domestic contracts. This yields, for each province, both gross residential volume and TRV-based indicators. In Lazio and Sicily, where such detailed information is not available, residential indicators are based on gross residential volume only.

3. **Aggregation and construction of residential indicators.**
   The hybrid-classified building stocks are aggregated at provincial level. For the residential classes (RL, RM and R), total volume is linked to census-based population and household counts to derive indicators such as residential volume per capita and per household. These indicators are then combined with ARERA provincial electricity demand for domestic low-voltage users to compute annual demand per household and per cubic metre of residential volume (using both gross volume and TRV where available).

4. **Linkage with sectoral electricity statistics.**
   Annual electricity consumption by sector from RAEE is compared with the distribution of building volume across PA, SP, tertiary (TC/TH/TT) and residential classes. This cross-sector comparison is used to identify sectors that occupy relatively little space but account for a large share of electricity demand, providing a simple measure of volumetric intensity at regional scale.

Figure 3.1 summarises this methodological framework. It highlights the progression from data collection and standardisation, through hybrid classification and TRV calculation, to the construction of residential demand and intensity indicators and their comparison with sectoral electricity statistics. The subsequent sections of this chapter describe each component of the framework in more detail and link them to the results presented in Chapter 5.

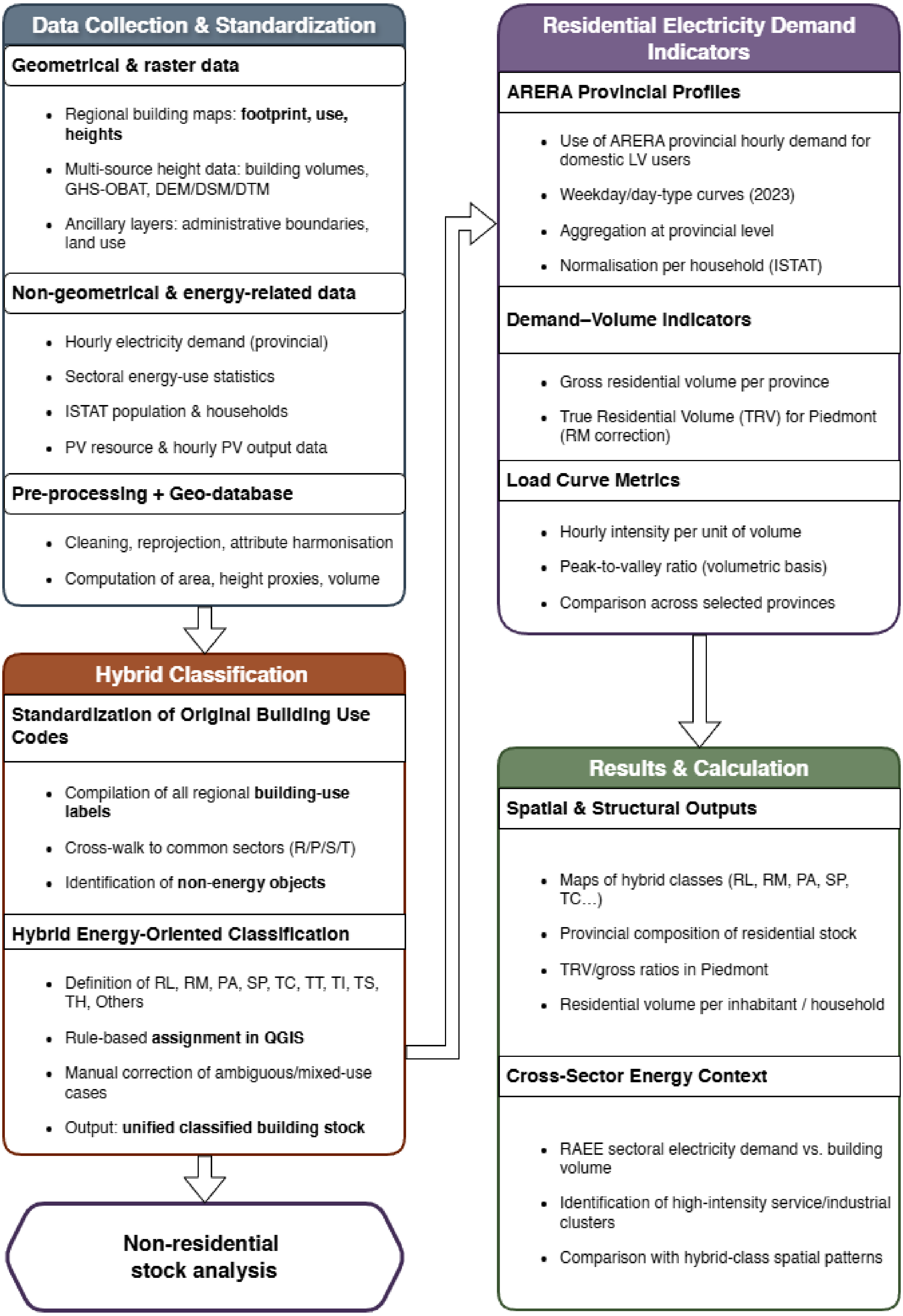


Figure 3.1 Research Design Flowchart (Source: Authorship)

3.2 Energy-Oriented Hybrid Classification of the Building Stock

The Italian regional technical maps provide very detailed spatial information on individual buildings, but the original uso attributes are heterogeneous and only loosely related to energy use. To support the analysis of provincial load curves and the construction of volumetric demand indicators, this thesis introduces a hybrid classification that links building function with indicative temporal patterns of electricity demand. The approach remains deliberately simple: it does not attempt to reconstruct full end-use profiles for each building, but it groups buildings into a limited number of categories that share similar operating schedules and load-shape characteristics, in line with evidence from empirical load-profile studies.

Recent work on GIS-based mapping of building electricity demand shows that combining building function with typical operating hours is sufficient to recover the main differences between residential, commercial, industrial and tourism-related loads. Ferrari et al. (2023) derive hourly demand profiles for a Mediterranean island by distinguishing residential dwellings and holiday homes and show clear seasonal and daily differences between these uses, with stronger evening peaks in summer weeks driven by tourism. At a broader scale, the ELMAS dataset provides more than 55,000 hourly electricity profiles for industrial and tertiary consumers in 42 countries, classified by NACE activity codes; clusters of offices, retail, manufacturing and other services display robust and distinct daytime, evening and 24/7 patterns. Methodological work on synthetic residential profiles likewise confirms that occupancy patterns and appliance sets generate systematic evening-oriented peaks for households, with variations across climate, dwelling type and socio-economic conditions. Building on this literature, the classification proposed here interprets the original uso information through a small set of behavioral descriptors that are meaningful for electricity modelling, while remaining compatible with the traditional R/P/S/T sectoral framework used in Italian statistics.

3.2.1 Defining Energy Consumption Types and Behavioral Descriptors

The starting point of the hybrid classification is the recognition that different building categories exhibit characteristic temporal patterns of electricity use. A substantial body of empirical work—based on smart-meter datasets, feeder measurements and sectoral consumption statistics—reports recurring load-shape features that are strongly linked to function, occupancy schedules and dominant end-uses.

Residential buildings typically show pronounced evening peaks and smaller morning peaks, reflecting occupancy patterns and domestic activities such as cooking, lighting and hot-water use. This behaviour is clearly visible in the residential load profiles reported for Mediterranean climates: permanent dwellings consistently follow a morning–evening pattern, whereas holiday homes exhibit lower winter demand and stronger summer daytime peaks driven by cooling (see **Figure 4.X** for winter and **Figure 4.Y** for summer profiles; adapted from Ferrari et al., 2023). These contrasts provide direct empirical motivation for differentiating standard residential (RL) from mixed/high-demand residential (RM) categories.

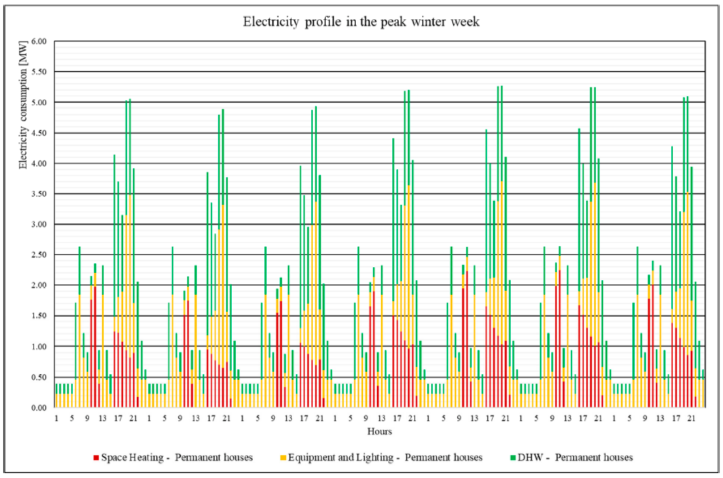


Figure 3.2 Winter residential hourly load profiles

Representative winter-week electricity demand profiles for permanent and holiday homes in Mediterranean climates. Adapted from Ferrari et al. (2023).

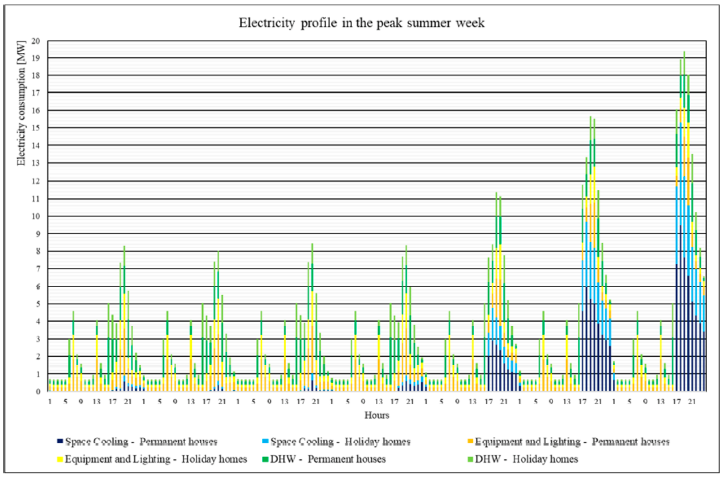


Figure 3.3 Summer residential hourly load profiles

Representative summer-week demand patterns showing strong cooling-related daytime peaks in holiday homes. Adapted from Ferrari et al. (2023).

Commercial and public-service buildings—such as offices, schools and shops—display strong daytime energy use concentrated between 08:00 and 18:00, with low night-time loads except for basic HVAC or IT standby. Industrial facilities, in contrast, often show 24/7 activity or explicit 2–3 shift patterns. Evidence from sectoral smart-meter studies (e.g., Bellinguer et al., 2024) highlights how agriculture, manufacturing, finance, education and health sectors maintain systematically different hourly, daily and weekly profiles (see **Figure 4.W**). For example, manufacturing exhibits plateau-like or stepped patterns linked to machinery and shift cycles, while financial and administrative activities follow tight daytime schedules.

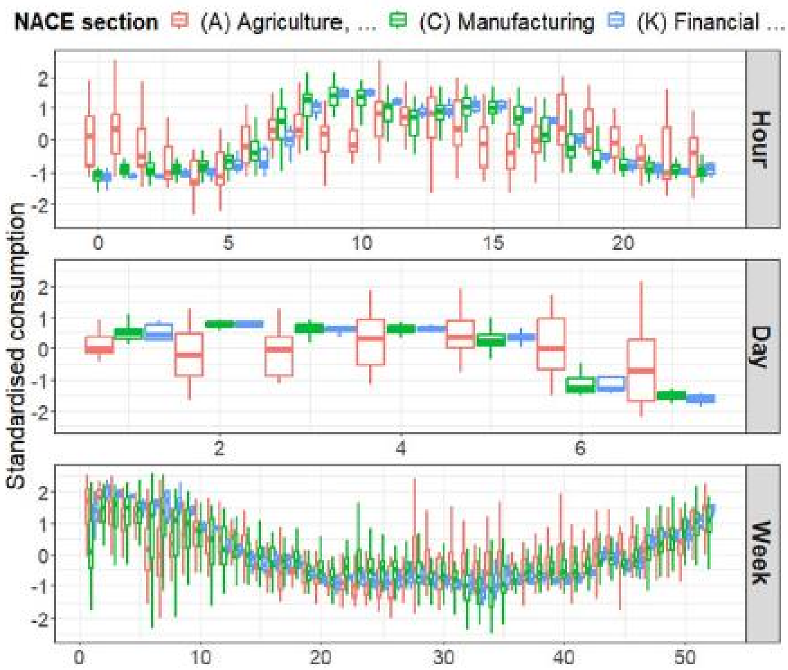


Figure 3.4 Hourly, daily and weekly load-shape variability by NACE sector

Standardized electricity consumption profiles for agriculture, manufacturing and financial/administrative activities. Adapted from Bellinguer et al. (2024).

Tourism-oriented and seasonal uses—including hotels, second homes, greenhouses and agricultural facilities—show distinctive seasonal dynamics. Summer peaks are often linked to cooling, tourism and irrigation, whereas winter periods may exhibit reduced activity. These seasonal dynamics align with the Seasonal Peaks descriptor used for PA and tourism-related tertiary categories.

Based on these recurring patterns, the thesis defines a controlled vocabulary of *behavioural descriptors* that summarise typical operating schedules, dominant loads, and qualitative features of the daily load curve:

- **Daytime peaks** – driven by working-hour activities (offices, schools, shops);
- **Evening peaks** – driven by residential and hospitality uses.
- **24/7 high demand** – driven by continuous operation (hospitals, data centers, critical infrastructure);
- **Shift-based demand** – driven by industrial production and process loads.
- **Seasonal peaks** – driven by tourism, agriculture and other seasonal activities.

Table X (Behavioral Descriptors) formalizes these descriptors by linking each behavioral category to representative building types, operating schedules, end-uses and indicative load-shape characteristics. The table operates as a conceptual bridge between the heterogeneous *uso* labels of regional technical maps and the temporal language adopted in subsequent load-curve construction.

Table 3.1 Behavioral Descriptors for Energy-Oriented Classification

Descriptor	Typical building types	Operational schedule	Main loads	Load-shape characteristics	Related hybrid classes
Daytime peaks	Offices, schools, shops, public administration	Weekdays, approx. 08:00–18:00	Lighting, HVAC, IT and office equipment	Single dominant daytime peak; very low night-time demand	TC, TS
Evening peaks	Dwellings, small hotels, restaurants, leisure venues	Mainly 18:00–24:00; secondary morning activity	Lighting, appliances, cooking, domestic hot water	Morning and evening peaks; reduced mid-day load	RL, RM, part of TI

24/7 high demand	Hospitals, major transport hubs, some student housing	Continuous 24-hour operation	HVAC, elevators, medical devices, security and critical systems	High, relatively flat base load maintained over 24 hours	TH, TT (major hubs), part of RM
Shift-based demand	Factories, production plants, large warehouses	Two or three shifts (e.g., 06–14, 14–22 or 24/7)	Machinery, process loads, ventilation, industrial lighting	Plateau-shaped or stepped profile aligned with shifts	SP
Seasonal peaks	Greenhouses, tourism facilities, seasonal farming buildings	Seasonal operation (summer/winter cycles; tourist season)	Heating, cooling, irrigation, process loads	Strong seasonal variation; very low off-season load	PA, tourism-related TC/TI

3.2.2 Terminology and Classification Logic

On top of the behavioral descriptors, the thesis defines a concise hybrid typology that combines:

1. **Sector** – the traditional R/P/S/T dimension (Residential, Primary, Secondary, Tertiary).
2. **Energy consumption type** – a second letter indicating typical demand intensity or sub-type.

The resulting codes (RL, RH, PA, SP, TC, TH, TT, etc.) translate heterogeneous *uso* strings into a small number of **energy-oriented classes**. For example:

- **RL** groups standard residential dwellings with conventional contract power and typical evening-peaked demand.

- **RH** identifies energy-intensive or high-amenity residential buildings (elevators, extensive cooling, large appliances), expected to have higher and more continuous loads.

- **PA** covers agriculture and extraction uses where electricity demand is strongly seasonal.

- **SP** groups manufacture and heavy industry with 24/7 or shift-based demand.

- **TC, TH, TT** capture different types of tertiary activities with daytime or mixed patterns (e.g. offices, schools, health facilities, tourism).

The logic behind this typology is consistent with sector-specific evidence reported in recent profiling studies. Ferrari et al. (2023) show that mapping use-category percentages and occupancy in a GIS framework can reproduce localized peaks related to seasonal tourism and cooling loads. Bellinguer et al. (2023) demonstrate that clustering NACE-coded customers yields clear groups with office-like daytime profiles, retail-oriented evening activity and industrial 24/7 loads. Residential simulators such as ResLoadSIM2.0 further confirm that differences in appliance stock and contracted power translate into families of low- and high-demand household profiles.

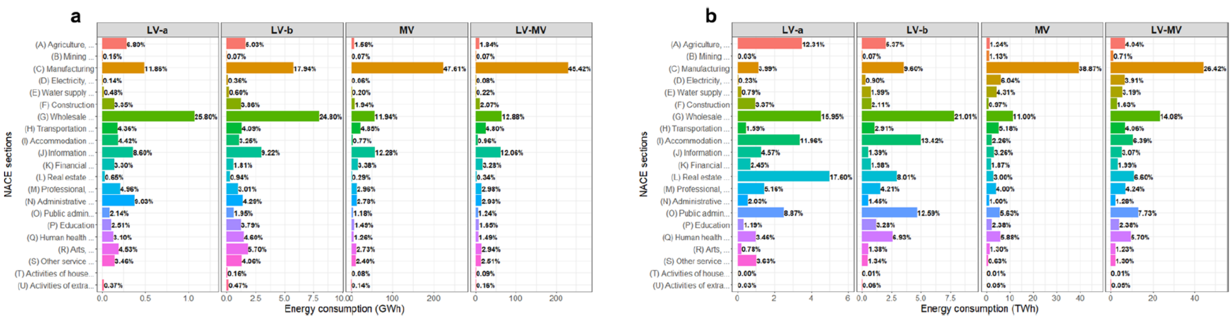


Figure 3.5 Sectoral electricity consumption patterns across NACE categories

(adapted from Bellinguer et al., 2024). Distinct consumption structures between manufacturing, accommodation, retail, education and health services support the differentiation of SP, TC, TI, TS and TH in the hybrid typology.

Rather than assigning an exact synthetic curve to each class, the present work uses these empirical insights **qualitatively**. The hybrid codes encode expectations about when electricity is mainly used (day vs. night, weekday vs. weekend, winter vs.

summer) and how intense it is, without fixing a unique curve shape. This is sufficient for:

- harmonizing regional building datasets under a common energy-oriented language.

  supporting later comparison between spatial distributions of classes and observed provincial load-curve indicators (e.g., peak-to-valley ratios);

- structuring scenario discussions on which parts of the stock are most compatible with residential REC schemes.

The complete hybrid typology used in this thesis is summarized in Table 3.2, which lists for each code the sector, consumption type, typical examples and associated behavioral descriptor.

Table 3.2 Final Hybrid Building Typology (R/P/S/T + Energy Demand)

New Code	Sector (R/P/S/T)	Energy Consumption Type	Examples	Energy Characteristics
RL (Residential - Low Demand)	R (Residential)	Only residential	Apartments, houses, dormitories	**Pure residential: morning and evening peaks, low daytime demand**
RM (Residential - High Demand)	R (Residential)	Mixed-use residential	Student dorms, Gated communities; Mixed-use residential with offices, shops on lower floors	**High demand. Similar to RL, but with higher daytime consumption due to mixed residential and commercial use. HVAC**
PA (Primary - Agriculture	P (Primary)	Agriculture, Mining, Fishing	Farms, greenhouses, fisheries, mines	**Seasonal peaks, heating, irrigation, refrigeration**

& Extraction)				
SP (Secondary -Production & Industry)	S (Secondary)	Manufacturing & Heavy Industry	Factories, refineries, warehouses	**Heavy machinery, continuous or shift-based operation**
TC (Tertiary - Commercial & Public Services)	T (Tertiary)	Shops, offices, government, musem, places of culture, military, hotel, religious, medical outpatient	Shops, banks, offices, administrative buildings, supermarkets, gyms, cinemas, church, military, police station, prison, dental clinic, family practice	**Daytime peak (offices, shops). High HVAC and lighting demand; stable operation of IT and service systems. Some facilities (e.g., churches, police stations) operate also during weekends.**
TT (Tertiary - Transport)	T (Tertiary)	Transport hubs	Train stations, airports	**Large transport hubs operate daily or 24/7. Main energy uses: lighting, HVAC. Load pattern follows passenger traffic.**
TI (Tertiary – Intermittent Use)	T (Tertiary)	Entertainment, stadium	Theatres, auditoriums, stadium, sport field, tennis court	**Very high peak loads during events but low or near-zero otherwise. Usage concentrated on specific hours/days (e.g., concerts, sports).**

TS (Tertiary - School)	T (Tertiary)	Schools	Primary and secondary schools, universities, training centers	**Daytime use, HVAC, lighting, no weekend use, seaonal**
TH (Tertiary - Healthcare)	T (Tertiary)	Hospitals	General hospital, specialized hospital, children's hospital	**Continuous 24/7 use. High demand from lighting, air conditioning, medical devices, and support systems, high hot water demand**
Others	-	Infrastructure or undefined features (non-building)	Telecom towers, open equipment areas, track platforms, technical shafts, or elements with NULL attributes	**There is no energy-use, or it isn't a builing**

3.2.3 Sources and Theoretical Basis

The rationale behind the hybrid classification is primarily grounded in the **well-documented energy-use behaviors of Italian buildings**. Sectoral energy balances (ENEA, Terna, ARERA) consistently show that electricity demand in Italy varies systematically across **building uses**, reflecting differences in operating hours, internal loads, and seasonal activity. Residential buildings are characterized by strong evening peaks and climate-sensitive summer cooling loads; offices, schools and administrative services concentrate consumption during daytime; industrial facilities exhibit continuous or shift-based profiles driven by machinery; and agriculture, tourism and greenhouse activities produce pronounced seasonal variability. These patterns form the core theoretical basis for the behavioral descriptors introduced in Section 4.2.1.

The hybrid typology therefore originates from **empirical Italian sectoral patterns**, rather than from external modelling frameworks:

Residential sector: evening-oriented demand with secondary morning peaks, strongly modulated by occupancy and appliance use (ARERA).

Tertiary sector: daytime peaks associated with HVAC, lighting and IT loads (Terna sectoral consumption).

Industrial sector: flatter or stepped profiles linked to shift production (ENEA technical reports).

Primary sector: seasonal activity linked to irrigation, refrigeration and greenhouse heating (regional energy balances).

3.3 Treatment of mixed-use residential buildings and definition of True Residential Volume

3.3.1 Mixed-use residential buildings and contractual boundaries

In dense Italian urban areas, many residential buildings are mixed-use blocks where dwellings on the upper floors coexist with commercial or service activities on the ground floor (e.g. shops, pharmacies, cafés). For energy modelling, this raises a basic consistency question: how much of the built volume in such buildings is actually associated with residential electricity demand.

The Italian regulatory framework distinguishes electricity contracts for *clienti domestici* from non-domestic users and from "*altri usi*" in low-voltage tariffs. Domestic contracts (*utenze domestiche*) are defined by the energy regulator ARERA as supplies used to feed a main dwelling and its annexed premises (such as garages, small studios or agricultural rooms) through a single metering point. Commercial activities and common services in condominiums are instead normally supplied under non-domestic contracts (*utenze altri usi*), which explicitly target shops, offices, garages, storage spaces and the common meter of the building (staircase lighting, lifts, gates).

Italian suppliers also specify that electricity for common areas such as stairwells, basements and elevators must, by law, be contracted as *uso non domestico*, with a dedicated meter in the name of the condominium. As a result, ARERA's residential load profiles for *clienti domestici BT* and the statistics used in this thesis refer primarily to contracts labelled as domestic at POD level and exclude most ground-floor commercial premises and common services in mixed-use blocks.

If the goal is to build a building-based demand model that is coherent with these residential profiles, the "residential volume" associated with each mixed-use building should therefore exclude the portion of volume that is likely to be served by non-domestic contracts. This motivates the introduction of a corrected metric, the **True Residential Volume (TRV)**, which aims to approximate the volume that is effectively linked to residential contracts in mixed-use buildings.

Piedmont is the only region in this case study where the original building-use field distinguishes explicit mixed-use residential labels (e.g. *residenziale e commerciale*, *residenziale e produttivo*). This allows the residential stock to be split into purely residential buildings (RL) and mixed-use residential buildings (RM) and, in turn, to define TRV for the provinces of Piedmont. In Lazio and Sicily, the building-use fields only report generic residential categories (e.g. *abitativa*, *residenziale*), so mixed-use blocks cannot be identified and no TRV correction can be applied.

3.3.2 Computation of the True Residential Volume (TRV)

In the hybrid classification adopted in this thesis, RL buildings are defined as purely residential, while RM buildings are blocks where residential uses coexist with non-residential functions. For RL buildings, the entire geometric volume is assumed to be residential. For RM buildings, a simple geometric correction is applied to approximate the exclusion of a non-residential ground floor.

The working assumption is that non-residential activities in RM buildings occupy the whole ground floor, while upper floors are predominantly residential. For each RM building, the **True Residential Volume (TRV)** is then computed as:

$$\mathrm{TRV} = V_{\mathrm{geom}} - A_{\mathrm{footprint}} \cdot h_{\mathrm{gf}}$$

where:

- V_{geom} is the geometric building volume (m³),

- $A_{\text{footprint}}$ is the footprint area (m²),
- h_{gf} is representative ground-floor height (m).

For RL buildings, which are classified as purely residential, no correction is applied and TRV is set equal to the total volume:

$$\text{TRV}_{\text{RL}} = V_{\text{geom}}$$

The parameter h_{gf} is chosen to be consistent with typical ground-floor heights in the regional technical maps and with the height distributions observed in the building stock. The purpose is not to reproduce the exact layout of individual buildings, but to obtain a realistic order of magnitude for the non-residential share of volume in mixed-use blocks.

Once TRV is computed at building level, values are aggregated by province to obtain:

- gross residential volume (RL + RM),
- True Residential Volume (sum of RL volumes plus TRV of RM),
- the ratio TRV/gross residential volume.

These indicators are used in Chapter 5 to quantify how much nominal residential volume is removed by the correction in each province of Piedmont and to provide an alternative denominator for volumetric residential intensity indicators. In Lazio and Sicily, where RM buildings cannot be distinguished, residential volume indicators are based on gross residential volume only, and this limitation is explicitly stated in the comparative analysis.

3.4 Construction of provincial residential demand and intensity indicators

This section describes how provincial residential electricity demand is combined with household and building-stock metrics to derive the indicators presented in Chapter 5. The aim is to obtain simple, comparable measures of residential demand per household and per unit of built volume, and to explore how these indicators relate to the hybrid classification and to TRV.

Residential electricity demand is taken from ARERA's provincial statistics for *clienti domestici BT* for the year 2023. For each province in the three study regions, annual residential consumption (MWh) and hourly demand profiles are available. Socio-demographic information on population and households is taken from the 2021 ISTAT census. Residential volumes are obtained from the hybrid-classified building stock described in Sections 3.2 and 3.3, aggregated to provincial level.

For each province, three main groups of indicators are computed:

1. **Annual demand per household**

Annual residential electricity consumption is divided by the number of households:

$$I_{\mathrm{hh}} = \frac{E_{\mathrm{res}}}{N_{\mathrm{hh}}}$$

where E_{res} is annual residential electricity demand (kWh·yr^{-1}) and N_{hh} is the number of households. This yields an indicator in kWh/household·yr, which is used in Chapter 5 to compare the intensity of residential demand across provinces, independently of differences in population size.

2. **Annual demand per unit of residential volume**

To link demand with the built stock, annual residential consumption is divided by gross residential volume and, where available, by TRV:

$$I_{\mathrm{vol,gross}} = \frac{E_{\mathrm{res}}}{V_{\mathrm{res,gross}}} \text{and} I_{\mathrm{vol,TRV}} = \frac{E_{\mathrm{res}}}{V_{\mathrm{TRV}}}$$

where $V_{\mathrm{res,gross}}$ is the gross residential volume (RL + RM) and V_{TRV} is the True Residential Volume (Piedmont only). These indicators (kWh/m^3·yr) capture how much electricity is used per unit of built residential space and are sensitive to both building characteristics and occupancy patterns. In Piedmont, the comparison between gross-based and TRV-based intensities allows the effect of mixed-use corrections on volumetric demand to be quantified.

3. **Hourly volumetric intensity and peak metrics**

To explore temporal patterns, ARERA's hourly provincial load profiles are normalised using the residential volumes described above. For selected provinces, hourly demand per unit of volume is computed as:

$$i_{t,\mathrm{vol}} = \frac{P_t}{V}$$

where P_t is hourly residential demand (kWh·h⁻¹) and V is either gross residential volume or TRV. This yields volumetric hourly intensity curves (kWh/m³·h) such as those shown for Torino in Chapter 5.

From these curves, simple shape descriptors are extracted:

- a **peak-to-valley ratio**, defined as the ratio between the maximum and minimum hourly intensities over a typical day;
- a **day–night ratio**, comparing the average intensity during daytime hours with the average intensity during night-time.

These metrics are not used as formal calibration targets, but as qualitative indicators of how concentrated residential loads are in the evening and how deep the night-time valley is. In Chapter 5, they are interpreted together with RL/RM shares and TRV-based intensities to discuss how mixed-use structures and building volumes influence the apparent load density of the residential stock.

3.5 Sectoral comparison between electricity demand and building stock

The final step in the methodology is to place the residential analysis within a broader sectoral context. This section describes how regional electricity consumption by sector is compared with the corresponding building volumes, using the hybrid classification as a bridge between statistical categories and spatial data.

Annual electricity consumption by sector is taken from ENEA's *Rapporto Annuale sull'Efficienza Energetica (RAEE)* and from Terna's IMCEI statistics for the year 2023, aggregated to the regional level. Four sectors are considered consistently with the hybrid classification:

- **Residential**,
- **Services** (tertiary),
- **Industry**,
- **Agriculture and primary activities**.

On the building side, the hybrid classes described in Section 3.2 are re-aggregated into these four macro-sectors. Residential classes (RL and RM) are grouped under "residential"; industrial and manufacturing classes under "industry"; service and tertiary classes under "services"; and agricultural and primary-sector buildings under "agriculture". For each region, the total building volume in each sector is computed by summing the volumes of the corresponding hybrid classes.

Two groups of indicators are then derived for each sector and region:

1. **Shares of electricity demand and building volume**
    - the share of total regional electricity consumption attributed to each sector;
    - the share of total regional building volume represented by each sector.

These shares are used in Chapter 5 to construct bar charts comparing, for example, the volume fraction and the fraction of electricity demand associated with services in each region. The goal is to check whether the hybrid classification reproduces the broad structure of energy use suggested by statistics: for instance, whether a relatively small stock of service buildings concentrates a large share of electricity demand.

2. **Electricity intensity per unit of building volume**

For each sector and region, an electricity-intensity indicator is computed as:

$$I_{\text{sec}} = \frac{E_{\text{sec}}}{V_{\text{sec}}}$$

where E_{sec} is annual electricity consumption in the sector (kWh·yr^{-1}) and V_{sec} is the corresponding building volume (m^3). This yields sectoral intensities in kWh/m^3·yr, which are compared across sectors and regions using a logarithmic scale in Chapter 5.

Even if the statistical sectors and the hybrid classes are not perfectly aligned, these indicators provide a useful consistency check. Service buildings are expected to show higher electricity intensity than residential buildings, and agriculture is expected to appear as the least electricity-intensive sector per unit of volume. When this expected ranking is confirmed, it supports the idea that the hybrid classification and the underlying building volumes are compatible with observed patterns of electricity use.

At the same time, the sectoral comparison helps to interpret the role of the residential stock within the wider system. The results in Chapter 5 show that residential buildings dominate the built volume but do not dominate electricity consumption, especially in Lazio and Sicily, where a relatively small fraction of tertiary and industrial buildings concentrates a large share of demand. For REC-related planning, this suggests that detailed residential indicators (including TRV and volumetric intensities) should be read together with information on high-intensity non-residential "anchor loads", which can play a central role in the design of community-scale interventions.

4. Study Area and Data

This chapter describes the geographical context and the main datasets used in the analysis. It introduces the three study regions—Piedmont, Lazio and Sicily—and summarises the data sources that support the hybrid building classification and the construction of residential load profiles. The methodological treatment of these datasets is detailed in Chapter 3; here the focus is on data availability, spatial and temporal resolution, and the main limitations that condition the analysis.

4.1 Study regions: Piedmont, Lazio, Sicily

This thesis focuses on three Italian regions that together form a north–centre–south transect: Piedmont, Lazio and Sicily. They differ in geography, climate and economic structure and therefore in the composition and energy behaviour of their building stocks. Figure 4.1 locates the three regions within Italy and highlights the main metropolitan areas (Turin, Rome and the principal Sicilian cities).

Piedmont is a north-western region stretching from the Alpine arc to the Po plain. Its territory combines high-altitude areas with small settlements, an extended peri-urban belt and the dense urban fabric of the Turin metropolitan area. From an energy perspective, Piedmont has a diversified demand structure: residential and services together account for roughly 40 % of final energy consumption, while industry and transport each contribute about 30 %, with agriculture playing a minor role. The region's long industrial tradition and logistics corridors translate into a substantial stock of secondary-sector buildings alongside large residential districts and service buildings. Recent regional energy system models explicitly use this mix of sectors and climate conditions to explore long-term decarbonization pathways, underlining the relevance of Piedmont as a representative northern case for energy planning.

Lazio lies in central Italy and is dominated by the metropolitan area of Rome, surrounded by coastal zones, inland plains and hilly interiors. The regional economy is strongly service-oriented: Lazio is the second Italian region in terms of GDP and shows a high specialization in high-tech and knowledge-intensive sectors, public administration and cultural activities. This economic profile is reflected in a building stock where large public administrations, offices, universities, hospitals, cultural facilities and tourism-related buildings play a central role alongside extensive residential areas. The strong concentration of tertiary functions in Rome implies substantial daytime electricity demand in the service sector, with temporal patterns that differ from those of more residential or industrial provinces. For the purposes of this thesis, Lazio therefore provides a contrasting case to Piedmont: less industrial, more service-based and with a very large metropolitan core.

Sicily, the largest region in southern Italy and an island in the central Mediterranean, combines different climatic, socio-economic and building-stock conditions. The region is characterized by hot, dry summers and mild winters, with growing concerns about increasing cooling demand and associated risks of energy poverty. The building stock is comparatively older and often less energy-efficient, with a high share of masonry structures and multi-story residential buildings constructed before modern thermal regulations. Previous studies have used Sicily as a case study for regional-scale classification of the residential stock into archetypes for energy planning, highlighting both the potential for retrofit and the challenges linked to data quality and socio-economic constraints.

Taken together, Piedmont, Lazio and Sicily cover a wide spectrum of Italian climatic zones and urban–rural configurations. They include dense historic centers, post-war apartment blocks, industrial estates, tourism areas and dispersed rural settlements. This diversity is essential for testing whether the proposed hybrid classification can cope with heterogeneous "use" definitions, varied economic structures and different dominant end-uses, while still providing a coherent framework for comparing residential energy demand and REC potential across regions.

4.2 Data Sources

The analysis combines spatial datasets on the building stock with statistical information on population and electricity demand for Piedmont, Lazio and Sicily. Table 4.1 summarizes the main inputs and their providers.

Geometrical information on buildings comes from the regional technical maps, which supply polygon footprints and *uso* (use) labels and, in some cases, height or volume attributes. These layers are downloaded from the official geoportals of the three regions and form the basis for the hybrid classification and for calculating footprint area and volumetric proxies at building level. Administrative boundaries and census geometries from ISTAT are used to aggregate results at provincial and municipal scales and to link buildings to population and household data from the 2021 census.

The temporal dimension of electricity use is described through ARERA statistics on domestic customers, which provide annual, monthly and hourly residential electricity withdrawals by province and contractual power class. These data are used to construct provincial residential load profiles and to compute annual indicators such as demand per household and per unit of residential volume. Additional regional consumption figures by sector and industrial indices from Terna support the contextual analysis of how residential demand compares with industrial and service uses at regional scale.

Regional energy balances and energy-efficiency indicators from ENEA's *Rapporto Annuale sull'Efficienza Energetica* (RAEE) are used mainly to frame the results within the broader policy context and to quantify the relative weight of residential, tertiary, industrial and agricultural electricity demand. They do not enter directly into the building-level calculations, but they are essential for interpreting the sectoral comparisons presented in Chapter 5.

Table 4.1 Overview of datasets used in the study

Main spatial, statistical and energy datasets employed for the hybrid classification and residential demand analysis.

Input Data	Dataset / Variable	Provider	Reference Period	Link / Notes
Building Stock Geometry & Morphology				
Piemonte – Regional Technical Map (BDTRE)	Building footprints, uso, height/volume attributes (UN_VOL_AV_LOC)	Regione Piemonte – Geoportale Piemonte	2024	https://www.geoportale.piemonte.it
Lazio – Regional Topographic Database (DBTR)	Building footprints, uso, limited height attributes	Regione Lazio – Geoportale Regione Lazio	2024	https://geoportale.regione.lazio.it
Sicilia – Regional Technical Map / SITR	Building footprints, uso, floors/height where available	Regione Siciliana – SITR Sicilia	2013	https://www.sitr.regione.sicilia.it
Height & Morphology Data				

Input Data	Dataset / Variable	Provider	Reference Period	Link / Notes
GHS-OBAT Building Height Grid	Global building height grid	European Commission JRC	2015 / 2018 releases	https://ghsl.jrc.ec.europa.eu/ghs_obat.php
DTM – TINITALY	Digital Terrain Model	INGV – Istituto Nazionale di Geofisica e Vulcanologia	2021	https://tinitaly.pi.ingv.it/Download_Area1_1.html
DEM – COP-DEM / EU-DEM (EEA 10 m)	Digital Elevation Model （COP-DEM EEA-10 DGED）	Copernicus Data Space Ecosystem	2024	https://browser.dataspace.copernicus.eu/
Electricity Demand & Consumption Data				
Residential hourly electricity demand	Hourly load curves by province	ARERA	2023	https://www.arera.it
Sectoral energy consumption (IMCEI)	Monthly energy demand by NACE sector	Terna	2016–2024	https://dati.terna.it/fabbisogno/imcei

Input Data	Dataset / Variable	Provider	Reference Period	Link / Notes
National load & production statistics	Electricity demand & RES generation	Terna	2016–2024	https://www.terna.it
Socio-demographic & Administrative Data				
Population & households	Census population, households	ISTAT	2021 census	https://www.istat.it
Administrative boundaries	Italian administrative units	ISTAT / regional portals	latest available	https://www.istat.it

4.3 Preprocessing

The core spatial information on the building stock comes from the regional technical maps of Piedmont, Lazio and Sicily. These datasets provide polygon footprints for individual buildings together with a textual attribute describing their use (uso or destinazione d’uso) and, in some areas, additional fields reporting height, number of floors or construction volume. All three maps were downloaded from the official regional geoportals listed in Table 4.1, reprojected to a common CRS (EPSG: 32632) and imported into a unified QGIS project.

Although the three regions follow similar cartographic specifications, there are important differences in scale, reference period and attribute structure. Piedmont and

Lazio adopt “technical map” or “topographic database” standards that distinguish a wide range of building functions, whereas the Sicilian SITR uses a more compact set of categories with fewer explicit sub-types. The uso fields also mix pure functions (e.g. *industriale*, *biblioteca*) with compound or mixed entries (e.g. *residenziale e commerciale*, *uso misto di altro tipo*). Before any energy-related analysis, these heterogeneous labels had to be cleaned and harmonised.

Pre-processing of the building layers followed the general procedure described in Chapter 3. Isolated cartographic artefacts and non-built objects (such as technical shafts or road accessories) were removed, multipart geometries were dissolved, and a minimum-area threshold was applied to exclude very small features that are unlikely to host significant energy use. For all remaining polygons, footprint area was computed and stored in a new attribute field. At the end of this step, three regional layers were available, each representing the entire building stock of the region with standardised geometry and basic attributes.

The next step was to translate the original uso labels into the hybrid, energy-oriented classes introduced in Chapter 3 (RL, RM, PA, SP, TC, TT, TI, TS, TH and Others). For each region, a classification dictionary was created, mapping every unique uso value to one of the hybrid codes. The mapping was based on the semantic meaning of the Italian labels, on their associated activity sector and on the qualitative load-profile descriptors defined in Section 3.2. Ambiguous or mixed labels were checked manually and assigned according to their dominant function.

Table 4.2 reports a simplified version of the classification dictionary for Piedmont. For each hybrid class, it lists a selection of representative EDIFC_USO labels as they appear in the regional technical map. This excerpt illustrates how residential, primary, secondary, tertiary and transport-related buildings are grouped under the new codes. The complete one-to-many dictionaries for Piedmont, Lazio and Sicily, including all original labels, are provided in Appendix A–C (Tables A-1 to A-3). In the main text, Table 4.2 is intended to clarify the classification logic rather than to document every individual case.

Table 4.2 Representative mapping between regional uso labels and hybrid building classes (Piedmont)
Excerpt from the full classification dictionary used to translate original uso categories into the hybrid energy-oriented classes.

New_Code	***Typical EDIFC_USO labels (Piemonte – original)***
RL	*abitativa*; *residenziale*
RM	*residenziale e agricolo*; *residenziale e commerciale*; *residenziale e produttivo*; *residenziale e ricreativo*; *residenziale e ufficio pubblico*
PA	*agriculturale*; *allevamento*; *fattoria*; *fienile*; *stalla*
SP	*stazione di telecomunicazioni*; *centrale elettrica*; *depuratore*; *impianto di produzione energia*; *inceneritore*; *industriale*; *stabilimento industriale*
TC	*campeggio*; *amministrativo*; *biblioteca*; *carcere, istituto di pena*; *caserma*; *commerciale*; *laboratorio di ricerca*; *luogo di culto*; *mercato*; *municipio*; *museo*; *palestra*; *piscina coperta*; *rifornimento carburanti*; *rifugio montano*; *sede albergo, locanda*; *sede di banca*; *sede di centro commerciale*; *sede di supermercato, ipermercato*; *servizio pubblico*; *struttura alberghiera*; *strutture ricettive*; *uso misto di altro tipo*
TH	*sanità*; *sede clinica*; *sede servizi sanitari ASL*; *sede di ospedale*
TI	*cinema*; *ricreativo*; *teatro, auditorium*
TS	*istruzione*; *sede di scuola*; *università*
TT	*aereo*; *altro impianto di trasporto*; *deposito ferroviario per vagoni, rimessa locomotive*; *edificio accessorio alle strade*; *ferroviario*; *parcheggio multipiano o coperto*; *servizi di trasporto*; *stazione autolinee*; *stazione funivia*; *stazione marittima*; *stazione passeggeri aeroportuale*; *stazione passeggeri ferroviaria*; *stazione seggiovia*; *stazione skilift*; *stradale*
Others	*Non conosciuto*; *Non definito*; *altro*; *eliporto*

Once the dictionaries were defined, they were implemented in QGIS by creating a new attribute field *New_Code* in each regional building layer and applying a rule-based update using the look-up tables. This produced three harmonised, hybrid-classified building stocks, which are used in Chapter 5 for spatial statistics and in Chapter 6 for the construction of residential load profiles and REC-type scenarios. For interpretation, results are frequently aggregated at provincial level, matching the spatial resolution of the ARERA and Terna datasets used for energy-demand analysis.

5. Results

This chapter presents the main outputs obtained from the harmonized building-stock database and the energy-oriented hybrid classification. The analysis moves from a general description of the stock and its sectoral composition to more detailed residential indicators and, finally, to simple contextual comparisons with regional electricity statistics.

The first group of results concerns the spatial distribution of the hybrid classes in Piedmont, Lazio and Sicily. The reclassified buildings are aggregated by province and by macro-sector (residential, primary, secondary and tertiary), using the hybrid codes RL, RM, PA, SP, TC, TH, TT and Others. These maps and tables provide an overview of how regional economies translate into different mixes of buildings and floor area, and show where residential, industrial and service activities are concentrated. They frame the role of the residential stock within the wider built environment that could potentially participate in Renewable Energy Communities.

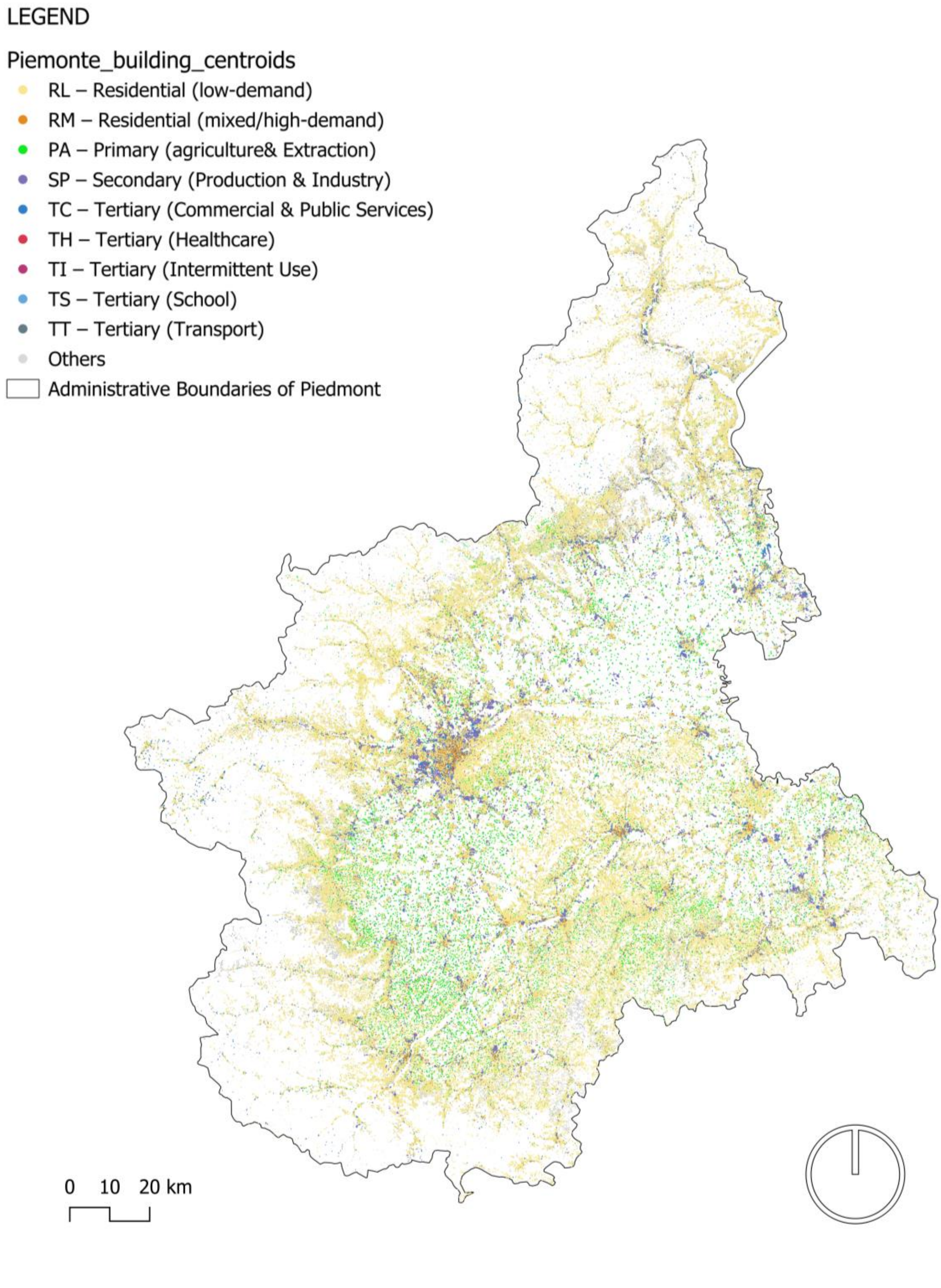
A second set of results links the building stock to national electricity statistics for all sectors. Annual RAEE data are used to compare the share of electricity consumption attributed to agriculture, industry, services and households with the share of building volume represented by PA, SP, TC/TH/TT and R in the three regions. This cross-sector comparison highlights which activities occupy relatively little space but account for a large fraction of demand and therefore behave as high-intensity or "anchor" loads.

The remainder of the chapter focuses on the residential sector. The distinction between purely residential buildings (RL) and mixed-use residential buildings (RM) is exploited in Piedmont to derive a True Residential Volume (TRV) that removes an assumed ground-floor non-residential layer from mixed blocks. Provincial residential demand from ARERA is normalized per household and per unit of residential volume, and simple indicators such as annual kWh per household, kWh per m^3 and peak-to-valley ratios are computed. For Lazio and Sicily, the coarser building-use fields only support a single residential class R and no TRV correction; this limitation is documented in the results and taken into account when comparing indicators.

5.1 Spatial Distribution of Hybrid Classes

As described in Chapter 4, building technical maps for Piedmont, Lazio and Sicily were downloaded from the respective regional geoportals and merged into three harmonised regional layers. The original *uso* attributes were translated into the hybrid codes (RL, RM, PA, SP, TC, TH, TT and Others) through region-specific dictionaries, so that every building polygon in the three regions carries a consistent energy-oriented class.

To visualise the hybrid classes at regional scale, each building polygon was converted to a centroid and mapped using a common colour palette. In these dot maps, each point represents one building, coloured according to its hybrid code. This makes it easier to read density and functional patterns over large territories, even where buildings are very small or closely packed. Because this representation hides the footprint size and volume, additional city-scale maps were produced for Torino, Roma and Catania, where the original building footprints are displayed with the same symbology. These zoom-ins provide a more detailed view of internal urban structure and mixed-use patterns at neighbourhood scale.



map 5.1 Hybrid building classes in Piedmont

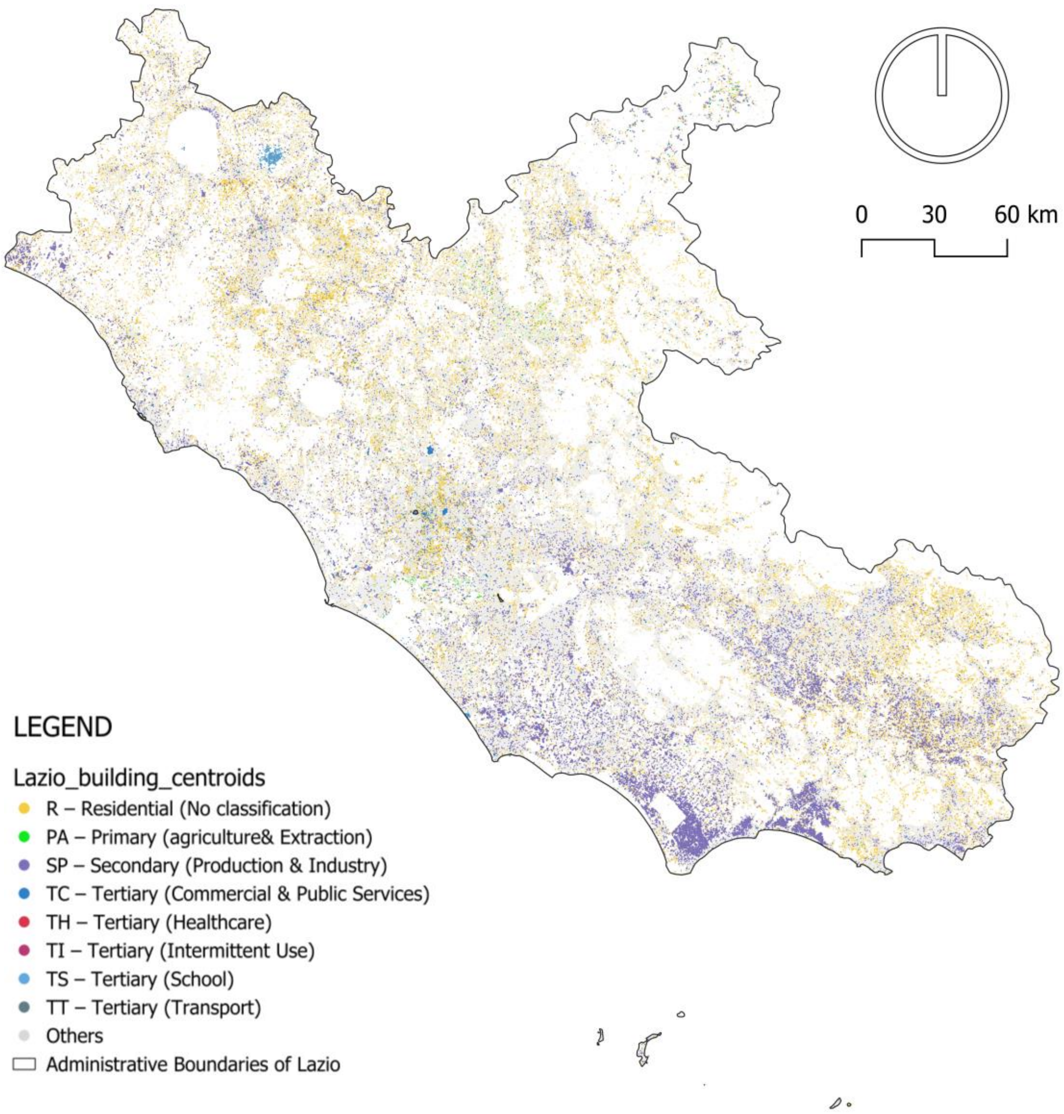
Regional distribution of building centroids classified by hybrid code (RL, RM, PA, SP, TC, TH, TT, Others)

map 5.2 Hybrid building classes in the Turin metropolitan area

Building footprints colored by hybrid code, illustrating mixed-use patterns in the historic core and surrounding residential neighborhoods.

In Piedmont, the regional map reveals a polycentric pattern of settlements. Clusters of residential buildings form around Torino and other medium-size municipalities, embedded in a more diffuse background of small towns and rural settlements. Primary-sector buildings (PA) appear mainly in valley bottoms and agricultural plains, while secondary-sector buildings (SP) follow the main transport axes and industrial corridors. Tertiary classes (TC, TH and TT) are concentrated in the regional capital and a few secondary service centres. The Turin zoom-in shows compact mixed-use areas in the historic core, where residential and tertiary buildings are interwoven, surrounded by larger belts of predominantly residential neighbourhoods.

In Lazio, the distribution is more clearly monocentric. The regional map is dominated by a large concentration of residential and tertiary buildings in and around Rome, with relatively sparse settlement patterns elsewhere. Within the metropolitan area, the zoom-in shows dense central districts where residential and TC/TH buildings are closely mixed, reflecting the coexistence of housing, offices, public administration and cultural functions. Moving outwards, the fabric gradually transitions to more



map 5.3 Hybrid building classes in Lazio

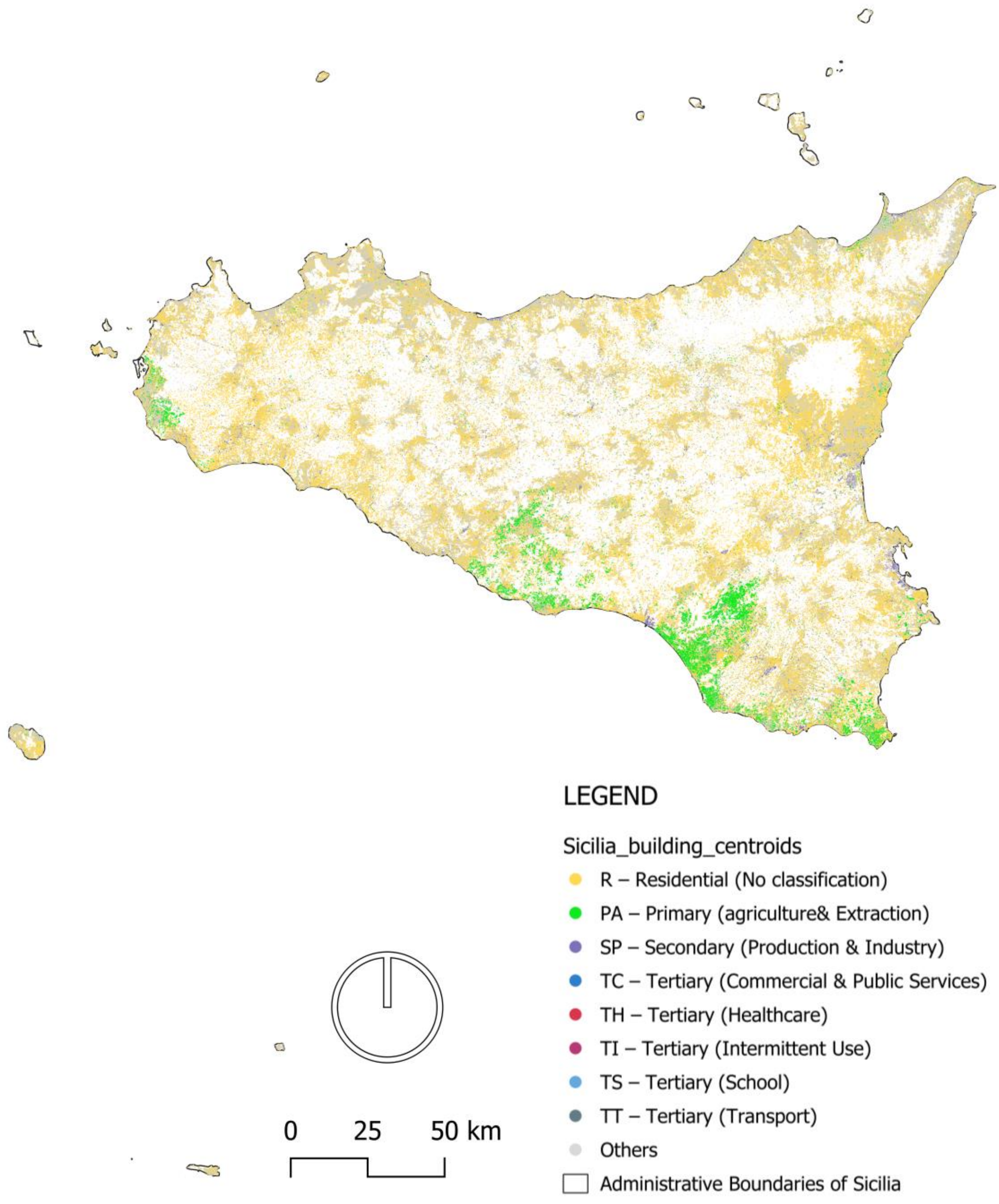
Regional distribution of building centroids classified by hybrid code (RL, RM, PA, SP, TC, TH, TT, Others).

homogeneous residential belts, punctuated by SP clusters along the main radial roads and coastal corridors, and by PA buildings in the inland agricultural areas.

map 5.4 Hybrid building classes in the Rome metropolitan area

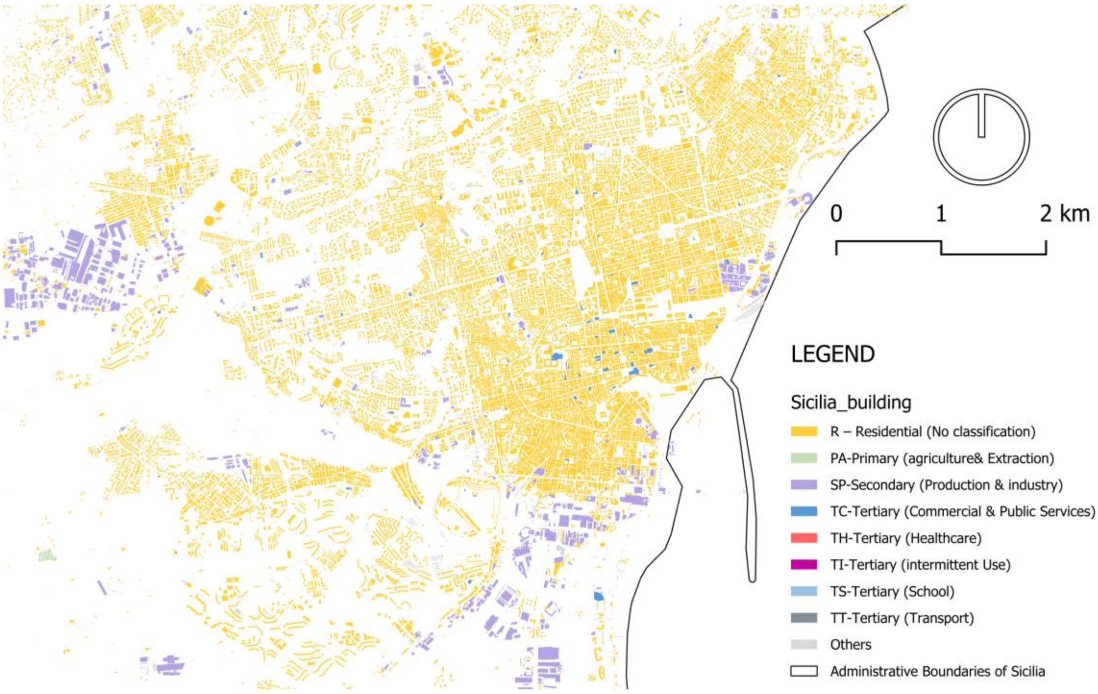
Building footprints colored by hybrid code, showing dense mixed-use central districts and surrounding residential belts.

In Sicily, the spatial pattern is more fragmented and strongly oriented towards the coast. The regional map shows compact metropolitan systems around Palermo, Catania and Messina, where residential and tertiary buildings form continuous urban areas. Outside these cities, settlement becomes more discontinuous, with small towns and villages separated by large tracts of rural land dominated by PA buildings. Secondary-sector buildings (SP) are mainly associated with ports, industrial areas and sections of the principal transport axes. Even without a zoom-in for every city, the regional representation clearly distinguishes the dense coastal conurbations from the low-density inland fabric.



Map 5.5 Hybrid building classes in Sicily

Regional distribution of building centroids classified by hybrid code, highlighting coastal conurbations and low-density inland areas.



map 5.6 Hybrid building classes in the Catania

urban area Building footprints coloured by hybrid code, showing compact residential and tertiary patterns along the coast.

Overall, the hybrid classification and the two-scale mapping approach make visible the contrast between urban concentrations of residential and tertiary functions and the more diffuse rural patterns where primary uses and low-density housing prevail. The maps in this section are deliberately descriptive and qualitative: they are intended to provide a visual context for the building stock, while more aggregated indicators on sectoral composition and residential structure are presented in the following sections.

5.2 Composition of the Residential Building Stock

Because residential demand is the main focus of the energy-modelling step, the composition of the residential building stock was analysed in more detail for the three study regions. In this thesis, residential buildings are defined as all polygons classified under the hybrid codes RL and RM in Piedmont and under the single residential class R in Lazio and Sicily. For energy-related indicators, the analysis is mainly based on building volume, which is used as a simple proxy for the amount of built space that can host residential electricity demand.

Residential buildings represent the majority of the building stock in all three regions, both in terms of number of buildings and in terms of total volume. However, the intensity and spatial distribution of residential development differ significantly between regions and between provinces. To capture these differences at the scale relevant for electricity statistics, residential volume was aggregated by province and linked to population and household data from the 2021 census. The resulting indicators provide a first quantitative picture of how much residential space is available per inhabitant or per household in each part of the study area, and they form the basis for normalising provincial electricity demand in the following sections.

5.2.1 Regional and provincial residential volume

Table 5.1 summarises, for each region, the total building volume, the share of this volume that is classified as residential, and two normalised indicators: residential volume per capita and per household. These indicators show how much residential space is available in relation to the resident population and to the number of households.

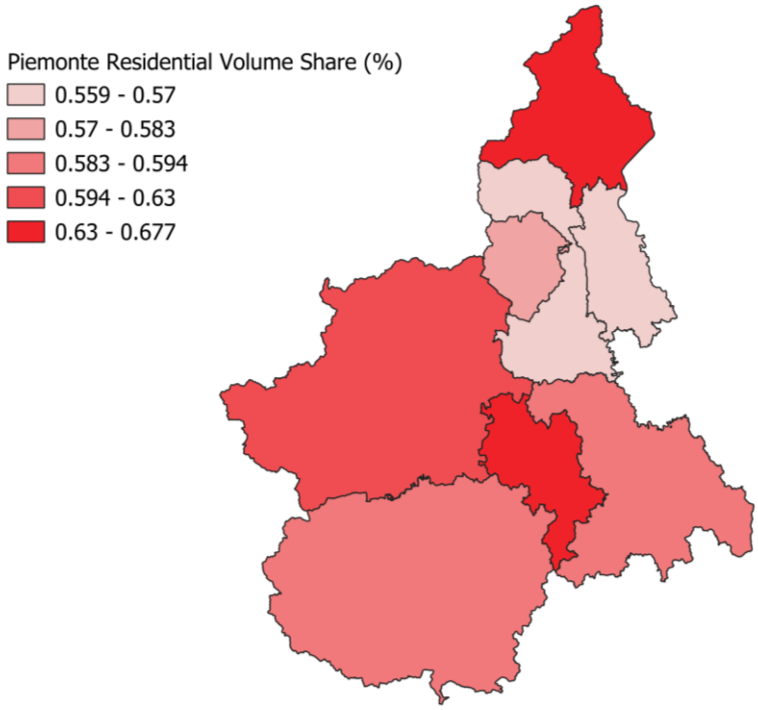
Table 5.1 Regional residential stock indicators

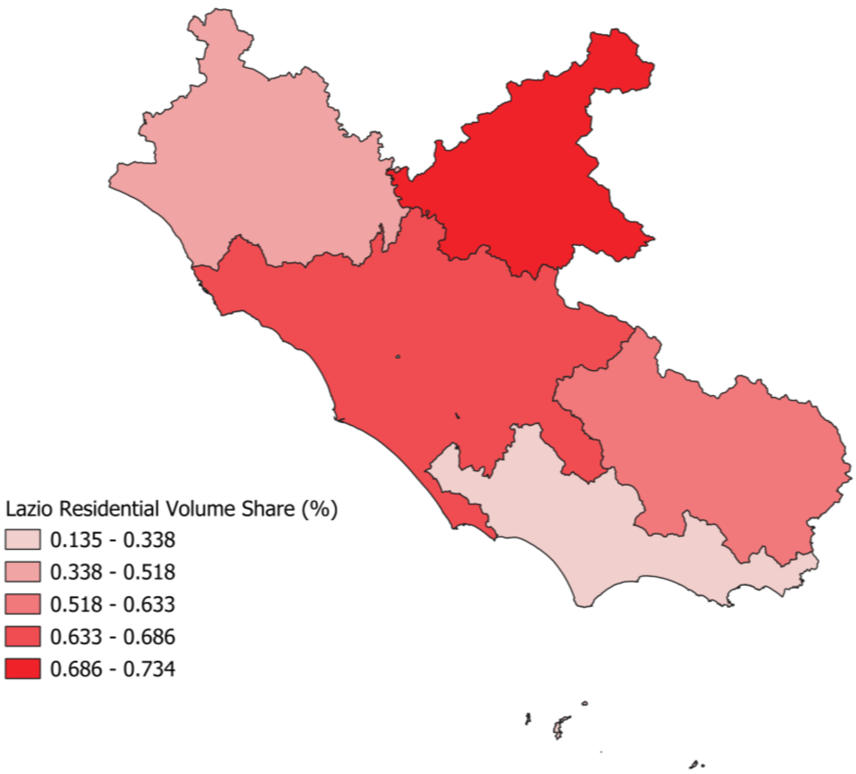
Total building volume, residential volume, and residential volume per capita and per household in Piedmont, Lazio and Sicily.

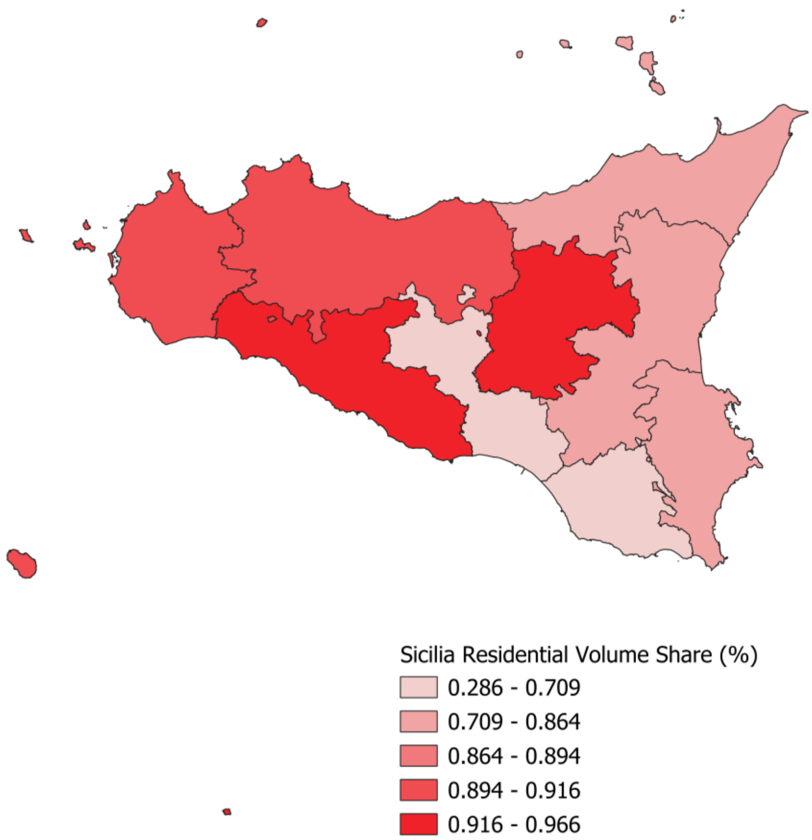
Region	*Total building volume (million m³)*	*Total residential volume (million m³)*	*Residential share (%)*	*Residential volume per capita (m³/person)*	*Residential volume per household (m³/household)*
Piedmont	2,118.06	1,356.35	64.0	303.3	699.3
Lazio	3,009.29	1,899.66	63.1	341.2	735.0
Sicily	2,291.60	1,967.31	85.9	427.2	1,022.8

The table confirms that residential buildings account for a dominant share of the built volume in all three regions. Residential volume represents around two-thirds of total building volume in Piedmont and Lazio and a higher share in Sicily, where the stock is more strongly dominated by housing. At the same time, the amount of residential space available per person and per household is not uniform. Lazio shows higher residential volume per capita and per household than Piedmont, reflecting a combination of larger dwellings in some suburban areas and a concentration of non-residential functions in central Rome. Sicily records the highest per-capita and per-household residential volumes, which is consistent with lower average population densities and more spacious housing in many small and medium-size municipalities.

To capture the spatial variability within regions, residential volume was also aggregated by province and linked to population and household data from the 2021 census. Two provincial indicators were calculated: the share of total building volume that is residential and the residential volume per capita. These indicators are mapped separately for Piedmont, Lazio and Sicily and are interpreted mainly in a comparative, within-region way, since the classification and data quality differ slightly between regions.


Piemonte Residential Volume Share (%)
0.559 - 0.57
0.57 - 0.583
0.583 - 0.594
0.594 - 0.63
0.63 - 0.677

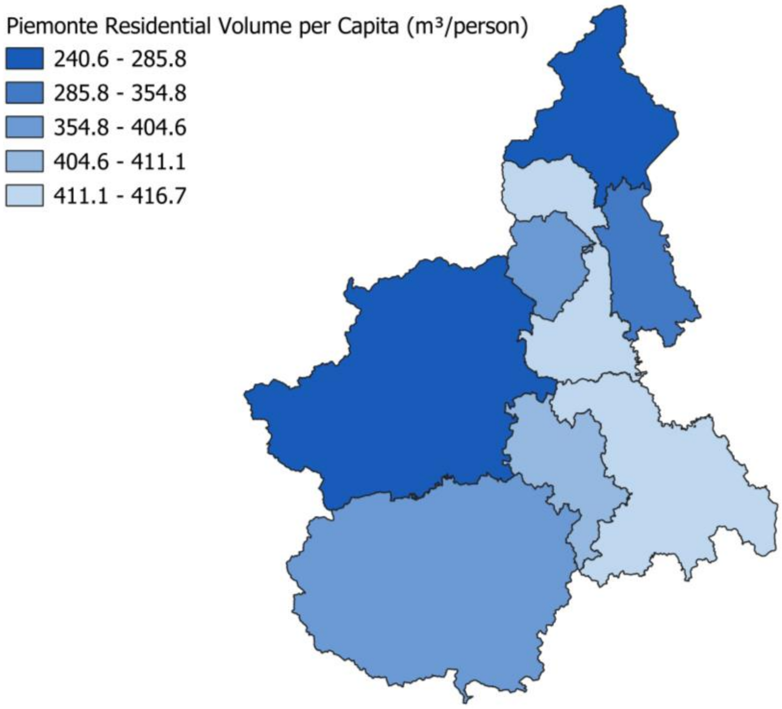

Lazio Residential Volume Share (%)
0.135 - 0.338
0.338 - 0.518
0.518 - 0.633
0.633 - 0.686
0.686 - 0.734

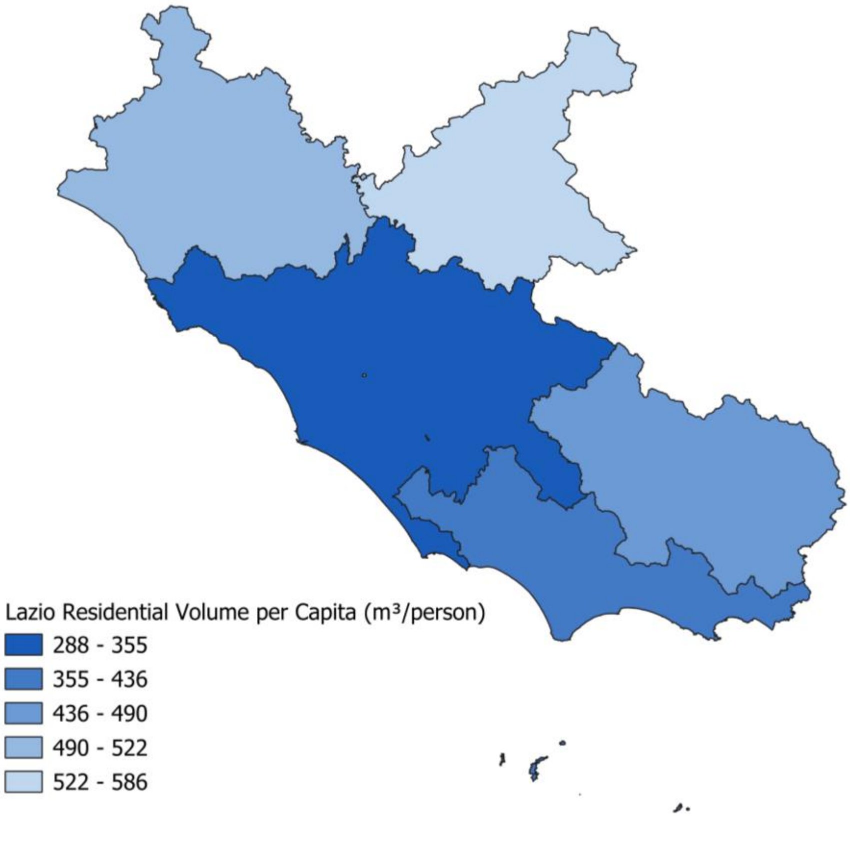


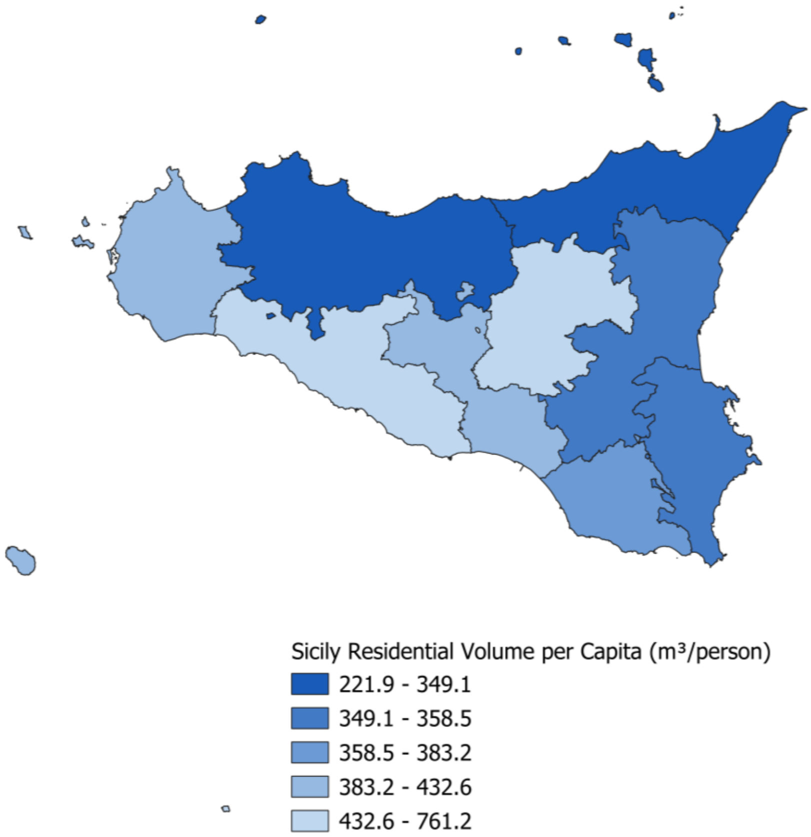
map 5.7 Residential building volume share (%) by province

(a) Piedmont; (b) Lazio; (c) Sicily. Provinces with higher residential volume shares generally correspond to areas where the building stock is more strongly dominated by residential uses.

In all three regions, provinces hosting the regional capitals concentrate large amounts of residential volume but also exhibit substantial non-residential stocks. As a result, their residential-volume shares are not always the highest in the region. In Piedmont, the Torino province combines a large absolute residential stock with an important industrial and tertiary base, so its residential share sits in the middle of the regional range. In Lazio, the province of Rome similarly mixes extensive residential districts with a dense core of offices, public administration and services. In Sicily, coastal provinces with metropolitan areas (Palermo, Catania and Messina) show slightly lower residential shares than some inland provinces, where the built stock is more strongly dominated by housing and agricultural buildings.


Piemonte Residential Volume per Capita (m³/person)
240.6 - 285.8
285.8 - 354.8
354.8 - 404.6
404.6 - 411.1
411.1 - 416.7


Lazio Residential Volume per Capita (m³/person)
288 - 355
355 - 436
436 - 490
490 - 522
522 - 586



map 5.8 Residential volume per capita by province

(a) Piemonte; (b) Lazio; (c) Sicilia. Darker shades indicate more residential volume per inhabitant.

The per-capita indicator reveals a complementary pattern. Provinces with high population densities, such as Torino and Rome, display lower residential volume per inhabitant, while more rural or less densely populated provinces tend to offer more residential space per person. In Piedmont, provinces like Cuneo and Verbano-Cusio-Ossola have relatively high residential volume per capita, reflecting smaller urban centres and more dispersed settlement structures. In Lazio, Viterbo and Rieti stand out compared to Rome. In Sicily, per-capita values are generally higher than in the other two regions but still differentiate between metropolitan provinces and more rural areas. These indicators do not provide a detailed typology of dwelling types or living conditions; they are used here as simple, comparable measures of the size of the residential stock and as a consistent denominator for provincial electricity demand in the following sections.

5.2.2 True Residential Volume in Piedmont

In dense Italian urban areas, many residential buildings are mixed-use blocks where dwellings on the upper floors are combined with commercial or service activities on the ground floor. For energy modelling, this raises the question of how much of the built volume in such buildings is actually associated with residential electricity demand, given that most ground-floor shops and common services are supplied under non-domestic tariffs.

Piedmont is the only region in this case study where the original building-use field distinguishes explicit mixed-use residential labels (e.g. *residenziale e commerciale*, *residenziale e produttivo*). This allows the residential stock to be split into purely residential buildings (RL) and mixed-use residential buildings (RM) and, in turn, to define a True Residential Volume (TRV) that excludes an assumed ground-floor non-residential layer in RM blocks.

For each RM building, the TRV is computed as:

$$TRV = V_{\text{tot}} - A_{\text{footprint}} \cdot h_{\text{gf}}$$

where V_{tot} is the geometric building volume, $A_{\text{footprint}}$ is the footprint area

h_{gf} is a representative ground-floor height.

For RL buildings, which are classified as purely residential, no correction is applied and TRV is set equal to the total volume.

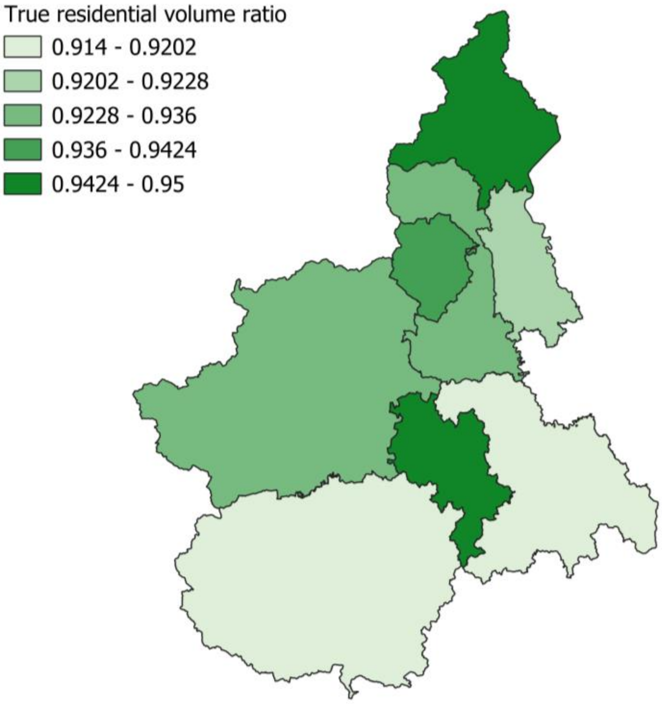
Table 5.2 True Residential Volume in Piedmont

Gross residential volume (RL + RM), True Residential Volume (TRV) and TRV-to-gross-volume ratio by province.

Province	***Gross residential volume (million m³)***	***True Residential Volume (million m³)***	***TRV / Gross***
Biella	62.30	58.57	0.940
Verbano-Cusio-Ossola	41.78	39.71	0.950
Torino	53.13	49.04	0.923

Vercelli	69.21	64.74	0.935
Novara	111.55	102.85	0.922
Cuneo	234.26	214.12	0.914
Asti	84.92	80.15	0.944
Alessandria	168.34	154.64	0.919

Table 5.2 reports, for each province in Piedmont, the gross residential volume (RL + RM), the corresponding True Residential Volume and the TRV-to-gross-volume ratio. Ratios range roughly between 0.91 and 0.95. Lower ratios are found in provinces with large mixed-use urban areas, such as Torino and Cuneo, indicating that a non-negligible share of the building volume in RM blocks is associated with non-residential ground-floor uses. Higher ratios characterise more rural or small-town



map 5.9 Piedmont True Residential Volume Ratio (%)

Ratio between True Residential Volume and gross residential volume for each province; darker shades indicate a larger share of mixed-use residential volume being excluded from TRV.

provinces, where purely residential buildings dominate and mixed-use blocks are less frequent.

Map 10 summarises the TRV-to-gross-residential-volume ratio at provincial scale in Piedmont. Ratios vary between 0.914 and 0.95: lighter shades indicate provinces where the TRV correction removes a larger share of volume, typically associated with a higher presence of mixed-use blocks, whereas darker shades correspond to provinces dominated by purely residential buildings (RL). Although the numerical range is narrow, the map confirms that the correction is not spatially uniform and tends to be more relevant in urbanised areas. This supports the interpretation of TRV as a more realistic proxy for the volume associated with residential electricity contracts and justifies its use as an alternative denominator for the volumetric intensity indicators discussed in Section 5.3.

For Lazio and Sicily, the original building-use fields only report generic residential categories (e.g. *abitativa*, *residenziale*) and do not allow mixed-use blocks to be distinguished from purely residential buildings. As a consequence, no TRV correction is applied and the residential volume indicators presented for these two regions are based on gross residential volume. When normalising provincial electricity demand, Piedmont can therefore be analysed using both gross residential volume and TRV, while Lazio and Sicily can only be assessed using gross residential volume.

5.3 Provincial Residential Load Profiles and Intensity Indicators

Using ARERA's provincial hourly demand data, monthly and day-type curves were constructed for all provinces in the three study regions. Demand was normalised on a per-household basis using ISTAT household statistics. This section links these temporal profiles with the residential volume indicators developed above, in order to obtain simple intensity metrics.

5.3.1 Annual residential demand per household and per residential volume

Table 5.3 reports, for each province, annual residential electricity demand, the number of households, gross residential volume and, for Piedmont, the True Residential Volume. From these inputs, three indicators are derived: annual demand per household (kWh/household·yr), per unit of gross residential volume (kWh/m³·yr) and, for Piedmont only, per unit of TRV.

Table 5.3 Annual residential electricity demand and intensity indicators by province

Annual residential demand, households, residential volume and derived indicators (kWh/household·yr; kWh/m³·yr; kWh/m³·yr based on TRV for Piedmont).

Province	Annual residential electricity (MWh)	Annual residential electricity (kWh)	Households	Gross residential volume (m³)	True residential volume TRV (m³)	kWh per household (kWh/household·yr)	kWh per m³ (gross) (kWh/m³·yr)	kWh per m³ (TRV) (Piedmont only)
Biella	152945.664	152945664	80192	62297400.83	58566718.96	1,907	2.455089008	2.611477417
Verbano-Cusio-Ossola	123962.5272	123962527.2	72756	41784139.24	39711320.45	1,704	2.966736409	3.121591672
Torino	1767216.938	1767216938	1032087	531302343.2	490407628.8	1,712	3.326198276	3.603567388
Vercelli	150359.6277	150359627.7	76427	69207454.6	64739675.27	1,967	2.172592946	2.322526752
Novara	324926.3871	324926387.1	160704	111549031	102852694.1	2,022	2.912857101	3.15914318
Cuneo	474786.5862	474786586.2	254899	234262064.4	214121013	1,863	2.0267327	2.217375024
Asti	184268.0309	184268030.9	93699	84921671.64	80145454.64	1,967	2.169858734	2.299170074

Alessandria	35416 6.1836	35416 6183.6	19334 4	16833 7820.9	15464 2771.3	1,832	2.1039 01439	2.2902 21395
Viterbo	27356 7.7213	27356 7721.3	14008 1	15641 0932.1		1,953	1.7490 31974	
Rieti	13343 9.2442	13343 9244.2	70252	88530 963.69		1,899	1.5072 60721	
Roma	38953 68.587	38953 68587	19093 47	12133 17358		2,040	3.2105 10887	
Latina	53806 4.69	53806 4690	23724 6	21085 2595.1		2,268	2.5518 52349	
Frosinone	43202 9.6725	43202 9672.5	19878 4	22550 9178.9		2,173	1.9157 96398	
Trapani	46207 7.7558	46207 7755.8	17958 2	16816 2880		2,573	2.7477 98776	
Palermo	12327 18.52	12327 18520	49274 4	26833 2493.1		2,502	4.5939 96446	
Messina	58397 5.0764	58397 5076.4	27189 3	20667 0549.8		2,148	2.8256 32762	
Agrigento	38379 2.6872	38379 2687.2	17236 6	19837 6119.6		2,227	1.9346 71814	
Caltanisset ta	21906 4.7865	21906 4786.5	10412 1	97724 423.94		2,104	2.2416 5851	
Enna	12783 8.1057	12783 8105.7	67904	11930 0757.9		1,883	1.0715 61556	

Catania	10536 51.369	10536 51369	44376 7	38076 5300.8	2,374	2.7671 93772
Ragusa	32211 6.5449	32211 6544.9	12915 6	11481 8213.9	2,494	2.8054 48143
Siracusa	41720 6.2925	41720 6292.5	16251 0	13788 3636.5	2,567	3.0257 85387

Across the three regions, annual demand per household clusters around 1,800–2,500 kWh/household·yr, with somewhat higher values in some southern provinces, consistent with the role of cooling loads. Volumetric intensities are generally modest, reflecting the large residential volumes involved, but reveal interesting differences between provinces and between regions. Metropolitan provinces such as Torino and Rome show relatively high kWh/m³ values, which can be interpreted as the combined effect of higher occupancy, smaller average dwelling sizes and a larger share of apartment buildings.

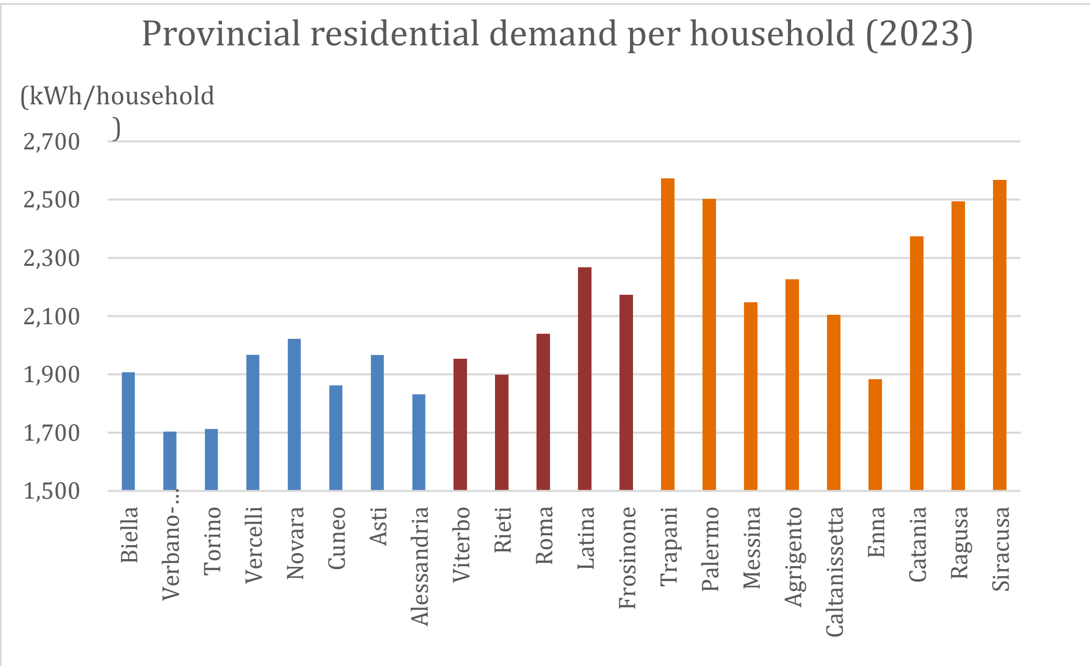


Figure 5.1 Provincial residential demand per household in Piedmont, Lazio and Sicily (2023)

Annual residential electricity demand per household by province; colours distinguish the three regions.

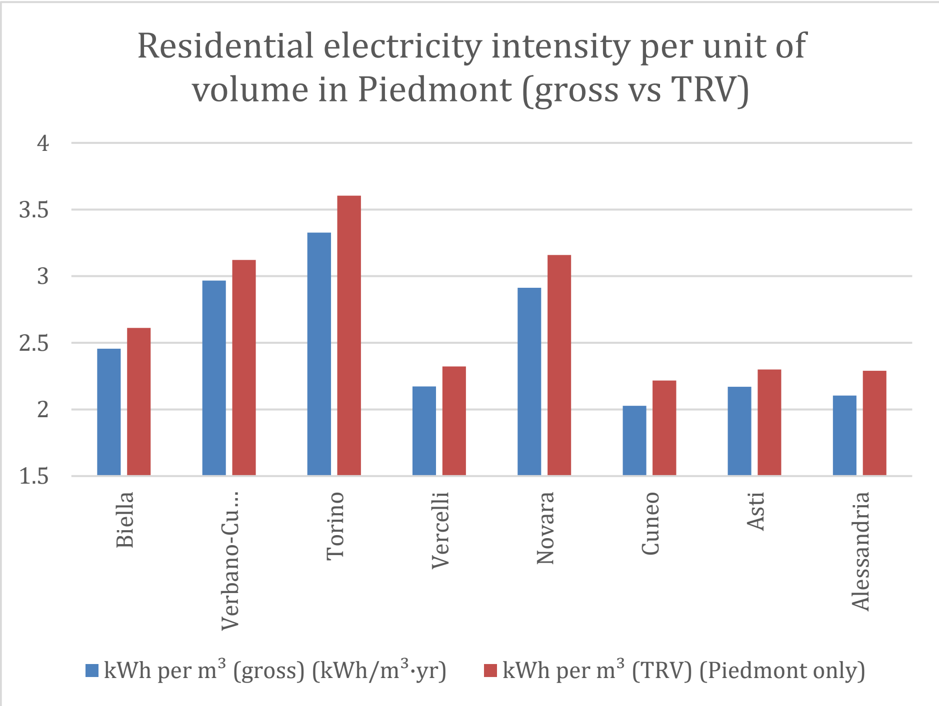


Figure 5.2 Residential electricity intensity per unit of volume in Piedmont (gross vs TRV, 2023)
Annual residential demand per cubic meter of residential volume, comparing gross residential volume and True Residential Volume (TRV).

In Piedmont, the use of TRV leads to systematically higher volumetric intensities compared with indicators based on gross residential volume. Removing the assumed non-residential ground-floor layer in mixed-use buildings produces a more concentrated estimate of residential demand, especially in dense urban cores where RM buildings are frequent. This confirms that gross residential volume may underestimate the effective residential load density in mixed-use areas and supports the use of TRV as a more appropriate denominator for intensity metrics.

5.3.2. Residential hourly load profiles at provincial scale

Hourly residential load profiles were derived from the ARERA dashboard "Prelievo dei clienti domestici per provincia", which provides withdrawals per domestic contract for each province, month and day type (weekday, Saturday, Sunday). To capture both seasonal and geographical variability, three representative provinces were selected: Torino for the North, Roma for Central Italy and Catania for the South. For each province, four months were analysed – January, April, August and October – corresponding respectively to winter, shoulder and summer conditions. Saturday and

Sunday profiles were averaged into a single holiday curve, so that each panel shows two curves per month (weekday and holiday).

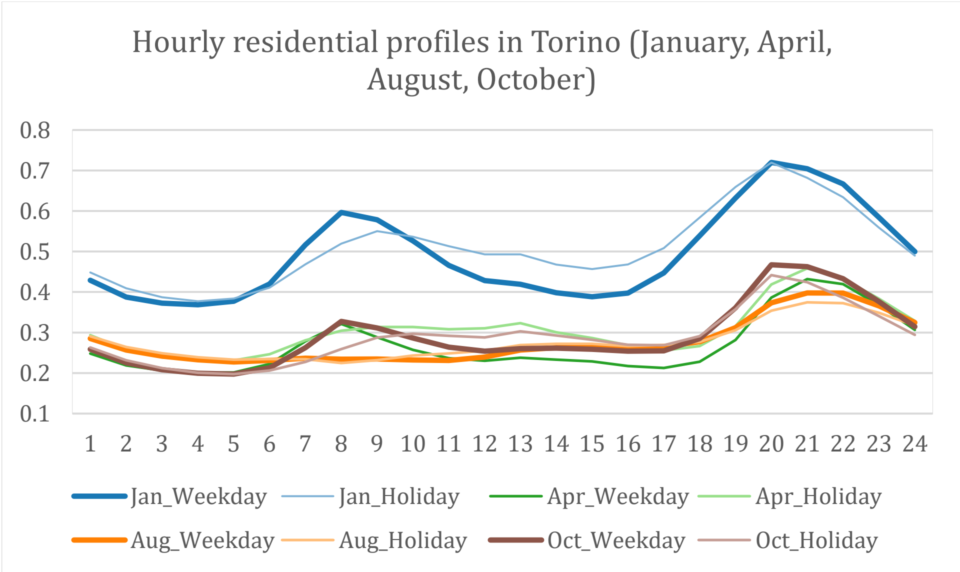


Figure 5.3 Hourly residential profiles in Torino

(January, April, August and October; weekday vs holiday)

In **Torino**, winter demand is clearly dominated by a pronounced evening peak between 19:00 and 21:00, especially on weekdays. Night-time values remain low and daytime loads are relatively modest, consistent with a cold-climate context where electric demand is mainly driven by heating, cooking and lighting. In April the profiles become flatter, with a smaller difference between night and day and a less sharp evening ramp. August shows only a moderate increase in afternoon and early evening consumption, suggesting that cooling loads are present but not dominant. October already starts to resemble the January shape again. Holiday curves are systematically higher than weekday curves during the central hours of the day, reflecting longer occupancy at home.

Roma presents a similar daily pattern but with smoother gradients. Night-time minimums are less pronounced, and the daytime plateau is higher than in Torino, both in winter and summer. The August profiles display a clearer afternoon increase compared with April and October, indicating a stronger contribution of cooling loads in the Roman climate. As in Torino, the difference between weekday and holiday profiles is visible mainly during mid-day, when weekend consumption remains higher.

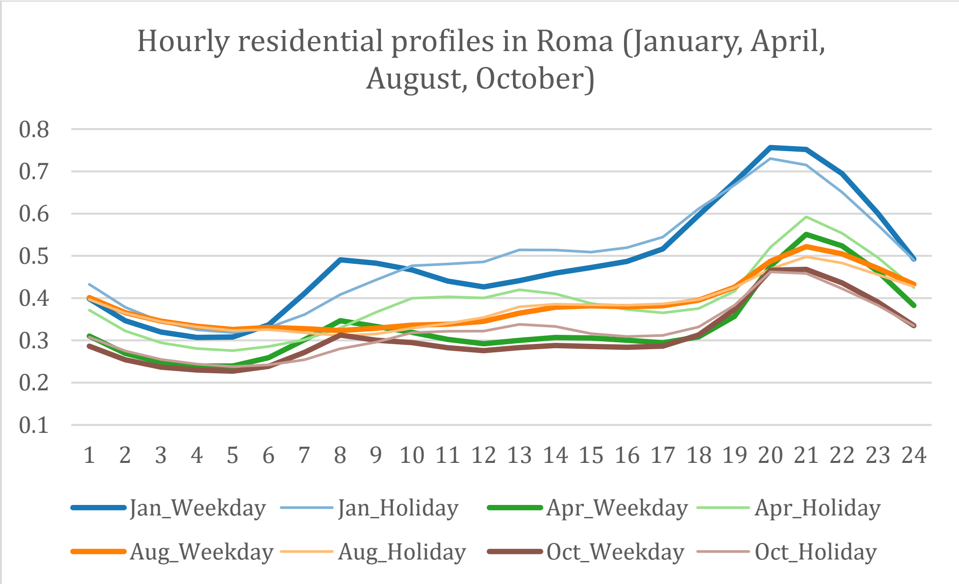


Figure 5.4 Hourly residential profiles in Roma

(January, April, August and October; weekday vs holiday)

In Catania, seasonal changes are more clearly driven by summer conditions. January profiles still show an evening peak around 20:00, but the winter contrast is smaller than in Torino. August exhibits the highest and most persistent loads over the afternoon and evening; both weekday and holiday curves start to rise earlier in the afternoon and remain high until late evening. The April and October curves remain

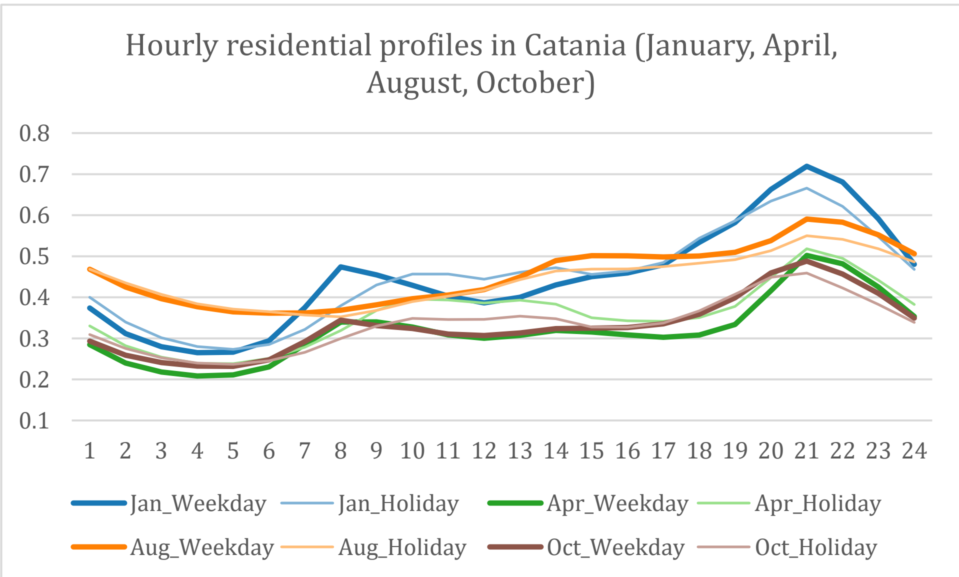


Figure 5.5 Hourly residential profiles in Catania

closer to the summer shape than to the winter one, confirming the milder seasonal cycle and the stronger role of cooling in southern coastal areas.

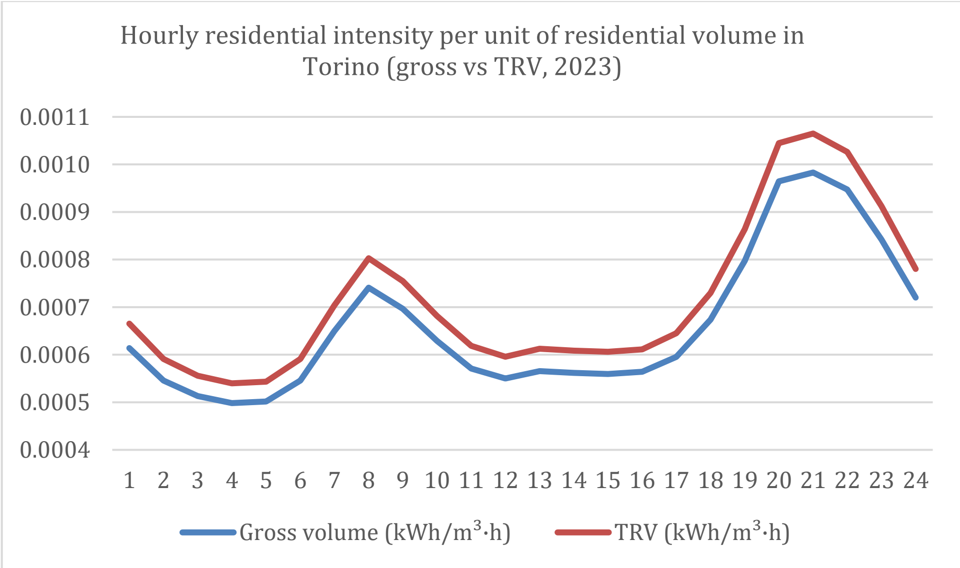


Figure 5.6 Hourly residential electricity intensity per unit of volume in Torino (weekday, 2023)

Gross volume vs True Residential Volume (TRV)

To link these temporal patterns with the volumetric indicators introduced in Section 5.3.1, the ARERA weekday profile for Torino was combined with the average residential volume per household calculated on both gross residential volume and on the True Residential Volume (TRV). Dividing the hourly withdrawal per contract by these two-volume metrics yields the hourly intensity per unit of volume ($kWh/m^3 \cdot h$) shown in Figure 5.6. The TRV-based curve is systematically above the gross-volume curve, with differences of the order of 7–12 % during the evening peak hours. This is expected, because the same provincial demand is concentrated on a smaller, strictly residential volume once mixed-use ground floors are removed. In dense mixed-use contexts, indicators based on gross volume therefore tend to underestimate the effective load density experienced by residential dwellings.

These hourly intensities complement the annual indicators presented in Section 5.3.1. Provinces that exhibit higher annual demand per household and per cubic metre also tend to show more pronounced evening peaks and higher daytime levels. The combination of ARERA hourly shapes with the residential volume and TRV metrics provides a simple time-resolved representation of demand per unit of residential stock, which will be used in Chapter 6 to explore the interaction between residential loads and PV generation in REC-type scenarios.

5.3.3 Discussion and implications for REC modelling

The indicators developed in this section show that both the structural characteristics of the residential stock and the temporal shape of electricity demand vary significantly between regions and provinces. At annual scale, demand per household and per cubic meter is higher in metropolitan provinces such as Torino and Rome, especially when intensities are calculated on the True Residential Volume. This confirms that mixed-use buildings concentrate residential demand in a smaller effective volume and that using gross residential volume would underestimate load density in dense urban cores.

At hourly scale, the ARERA profiles for Torino, Roma and Catania highlight the combined effect of climate and household behavior. Northern provinces are dominated by winter evening peaks, whereas in central and southern coastal provinces summer afternoon and evening loads become more prominent. For REC modelling, these differences matter for at least two reasons: they influence the coincidence between residential demand and PV production, and they change the level of stress imposed on storage or on the local grid. In Chapter 6, the REC scenarios are therefore built using both the volumetric indicators and the representative hourly profiles derived in this section, rather than a single "average" Italian curve.

5.4 Synthesis of residential demand patterns

This section integrates the spatial and temporal indicators developed earlier to provide a consolidated view of residential electricity demand across the three regions. The analysis combines the annual intensity metrics (Section 5.3.1) with the hourly withdrawal profiles (Section 5.3.2), highlighting the main geographical differences and identifying the elements that are most relevant for REC-oriented modelling.

At the regional scale, annual consumption per household and per unit of residential volume already suggests distinct patterns of energy use. Piedmont shows the lowest household demand among the three regions, consistent with its cooler climate and a larger share of single-use residential buildings. Lazio and Sicily exhibit progressively higher annual values, with Sicily reaching more than 2,500 kWh per household and the highest intensity per cubic meter. These differences reflect not only climatic conditions but also the structural characteristics of the building stock, occupancy patterns and electric heating or cooling prevalence. In Piedmont, the use of the True Residential Volume (TRV) leads to systematically higher volumetric intensities, showing that removing mixed-use ground-floor areas produces a more concentrated estimate of residential demand.

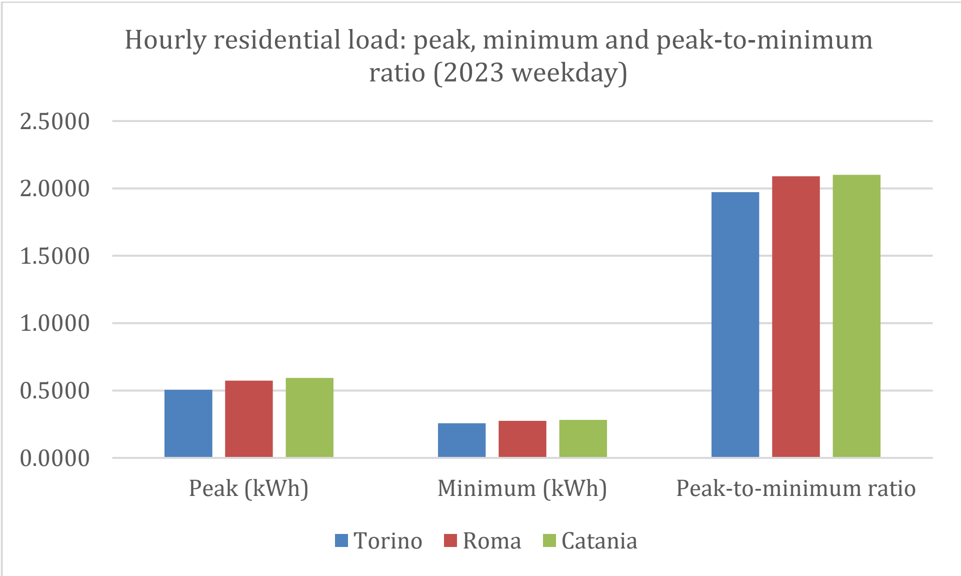


Figure 5.7 Hourly residential load: peak minimum and peak-to-minimum ratio

Daily maximum and minimum hourly withdrawals per residential contract and corresponding peak-to-minimum ratios for Torino, Roma and Catania (weekday, 2023).

To characterize temporal variability in a simple and comparable way, an hourly peak–to–minimum ratio was calculated for three representative provinces — Torino, Roma and Catania — using the 2023 ARERA weekday profiles. The indicator is defined as the ratio between the daily maximum and minimum hourly withdrawal per residential contract. Torino presents the lowest ratio (1.97), with a marked evening peak but relatively stable night-time and daytime levels typical of winter-dominated climates. Roma (2.09) and Catania (2.10) display a sharper contrast between night-time minima and afternoon–evening maxima, the latter driven mainly by summer cooling loads in southern regions. These patterns are coherent with the seasonal profiles shown in Section 5.3.2, where Catania exhibited the strongest summer afternoon rise and Roma presented a more pronounced late-evening peak compared to Torino.

The results emphasize that both **annual load density** (kWh/m^3) and **daily variability** (peak–minimum ratio) are essential descriptors of residential demand. The volumetric perspective captures the structural differences in the building stock, while the hourly indicators describe behavioral and climatic effects that shape the temporal alignment between demand and potential PV generation. Provinces with higher peak–to–valley ratios are expected to present greater temporal mismatch and, consequently, higher storage requirements in REC applications. The TRV-based volumetric intensities further indicate that in dense mixed-use urban areas the effective evening load density may be underestimated when gross residential volume is used. These implications provide the basis for the REC simulations developed in Chapter 6, where time-resolved load profiles are combined with PV production to explore the potential for energy sharing.

5.5 Sectoral electricity demand and high intensity uses

This subsection places the residential analysis in the context of the whole regional electricity system. Regional energy balances (RAEE) were combined with the P/S/T building volumes derived from the hybrid classification in order to compare, for each region, how much electricity is used by the main sectors relative to the share of built volume they occupy. The four sectors considered are residential, services (“civile”), industry and agriculture.

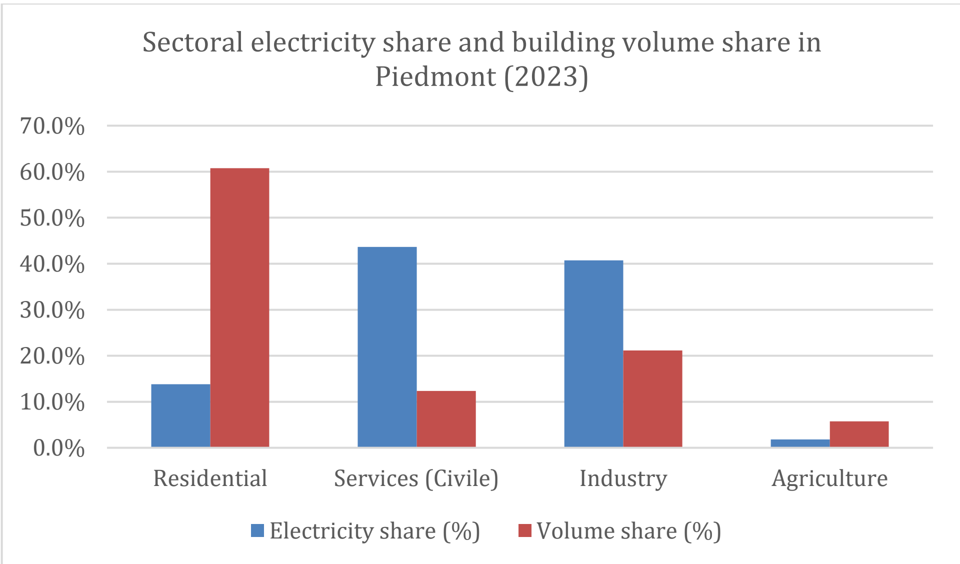


Figure 5.8 Sectoral electricity share and building volume share in Piedmont (2023)
Share of regional electricity consumption and share of building volume for residential, services, industry and agriculture.

Figures 5.8–5.10 show, for Piedmont, Lazio and Sicily respectively, the sectoral electricity shares against the corresponding shares of building volume. The mismatch between the two is evident. In Piedmont, residential buildings account for about 60 %

of the total volume but only around 14 % of regional electricity consumption. Services occupy roughly 12 % of the built volume yet absorb more than 40 % of electricity use, while industry is more balanced (about 21 % of volume and 40 % of electricity). Agriculture remains marginal in both dimensions.

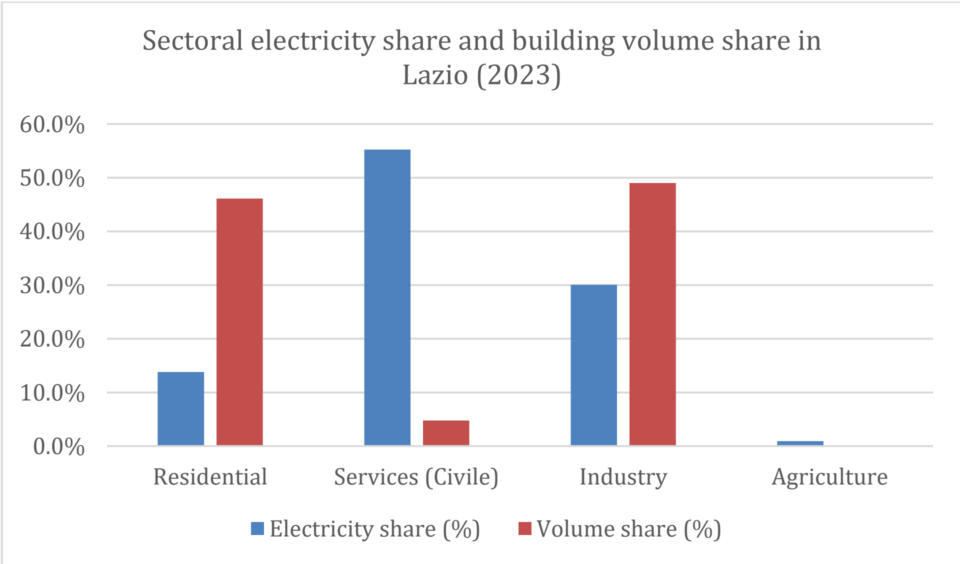


Figure 5.9 Sectoral electricity share and building volume share in Lazio (2023)
Share of regional electricity consumption and share of building volume for residential, services, industry and agriculture.

The contrast is even stronger in Lazio. Residential and industrial buildings together represent almost the entire building stock (about 46 % and 49 % of the total volume), whereas services represent only around 5 %. Nevertheless, services are responsible for more than half of regional electricity consumption, compared with about 30 % for industry and 14 % for residential uses. This confirms that a relatively small stock of tertiary buildings – offices, retail and other service activities – drives a disproportionate share of electricity demand in the region.

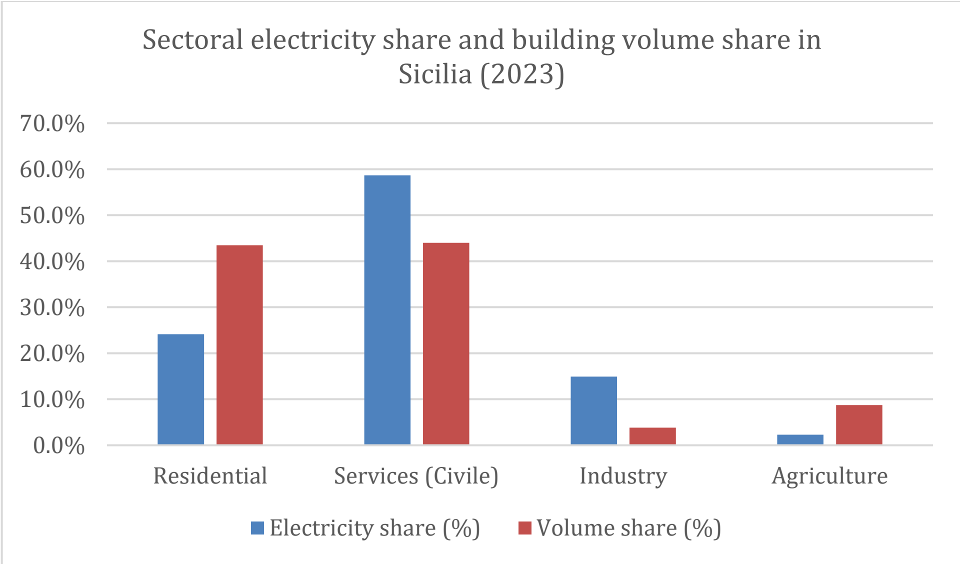


Figure 1.10 Sectoral electricity share and building volume share in Sicily (2023)
Share of regional electricity consumption and share of building volume for residential, services, industry and agriculture.

Sicily shows a slightly different configuration. Residential and service buildings contribute almost equal shares of the total volume (around 43–44 % each), and services again dominate electricity consumption with nearly 60 % of the total. Residential demand is relatively higher than in the other two regions (around one quarter of the total), while industry and agriculture play a minor role in terms of electricity use. The combination of a large tertiary stock and higher residential shares reflect the more urban and coastal concentration of electricity demand observed in Chapter 3.

To better characterize these imbalances, Figure 5.11 summarizes an electricity-intensity indicator for each sector and region, defined as annual electricity consumption divided by the corresponding building volume (kWh per m^3·yr, shown on a logarithmic scale). Despite differences in absolute values, the ranking of sectors is consistent across the three regions. Service buildings systematically exhibit the highest intensity, confirming their role as high-load users. Industrial buildings show intermediate intensities, while residential buildings are one order of magnitude lower and agricultural buildings remain the least electricity-intensive, although with higher relative uncertainty due to limited volumes.

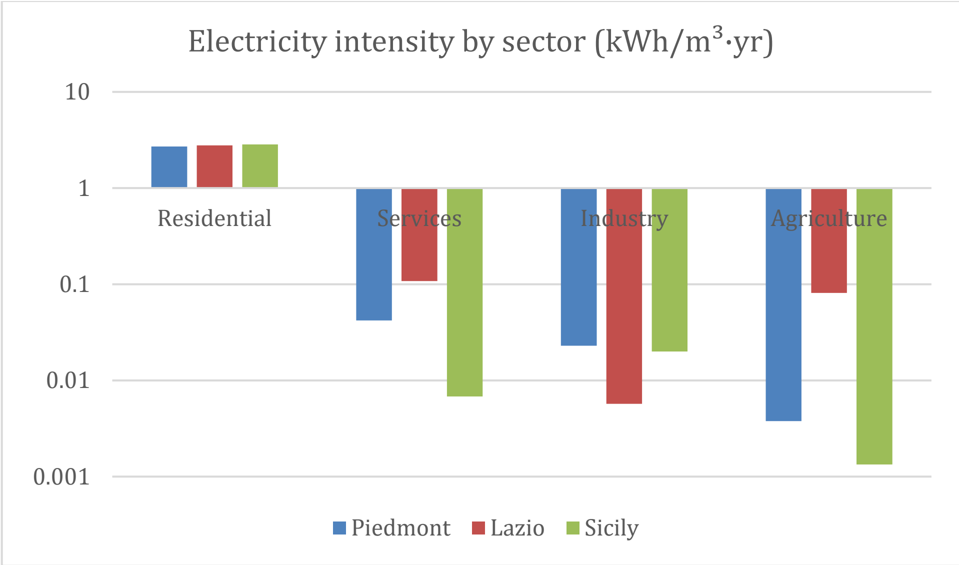


Figure 5.11 Electricity intensity by sector and region (kWh/m³·yr, logarithmic scale)
Annual electricity consumption per unit of building volume for residential, services, industry and agriculture in Piedmont, Lazio and Sicily.

Overall, this sectoral comparison highlights that the residential stock, which dominates the built volume, is not the main driver of regional electricity use. Instead, a relatively small fraction of tertiary and industrial buildings concentrates a large share of demand, especially in Lazio and Sicily. For the purposes of REC design, these results suggest that non-residential buildings can act as potential "anchor loads", around which residential demand – characterized in detail through the hybrid classification and TRV indicators – can be aggregated. In other words, the hybrid classification developed in this thesis provides a residential lens, while the RAEE-based sectoral analysis offers a complementary picture of where the most energy-intensive parts of the system are located within each region.

6. Discussion & policy implications

This chapter reflects on the main findings of the thesis and links them back to the initial objectives: building a hybrid, energy-oriented classification of the Italian building stock for three regions and using it to read residential electricity demand in a more spatially explicit way. The discussion is organised around four points: what the classification actually adds, what TRV changes in the notion of "residential volume", what emerges from the provincial residential indicators, and how these elements can inform REC-oriented planning.

6.1 What the hybrid classification adds

The first result of the work is that it is possible to harmonise three regional technical maps—Piedmont, Lazio and Sicily—into a single, energy-oriented classification without losing the main structure of the original *uso* fields. The hybrid codes (RL, RM, PA, SP, TC, TH, TT, Others) remain close to common planning categories, but they already give a clearer picture of how different types of buildings are distributed across space.

At regional scale, the maps in Chapter 5 show patterns that are consistent with the known geography of the three regions:

- in Piedmont, a polycentric system with industrial corridors along the main transport axes and a mix of residential and tertiary uses in and around Torino;
- in Lazio, a strongly monocentric structure dominated by Rome and its service-dominated metropolitan area;
- in Sicily, fragmented but dense coastal conurbations contrasted with large rural interiors.

This suggests that the hybrid classification is reading something real in the data, rather than just rearranging labels. It turns a very detailed but heterogeneous set of *uso* categories into a small number of classes that are easier to relate to energy use and to sectoral electricity statistics.

The classification is also useful on the residential side. By isolating residential classes (R, RL, RM) and aggregating them at provincial level, it becomes possible to talk about "residential volume per inhabitant" or "per household" in a way that is consistent across the three regions. These indicators are simple, but they already highlight the difference between metropolitan provinces with less residential volume per household and more rural or small-town provinces where residential space per household is higher.

6.2 TRV and the idea of residential volume

A second key contribution is the explicit treatment of mixed-use residential buildings in Piedmont through the definition of True Residential Volume (TRV). The starting point is the mismatch between building geometry and contractual boundaries: a mixed-use block with a ground-floor shop and several floors of flats is one building, but it almost never corresponds to one single domestic electricity contract.

By combining ARERA's definition of *clienti domestici* with the hybrid classification, the thesis argues that the ground-floor layer of RM buildings is more likely to be supplied under non-domestic contracts, together with common services such as stairwell lighting and lifts. The TRV indicator operationalises this idea by subtracting a representative ground-floor volume from RM buildings, while leaving RL buildings unchanged.

The effect of this correction is visible but moderate. Provincial TRV/gross ratios in Piedmont range roughly between 0.91 and 0.95, with lower values in more urbanised provinces where mixed-use blocks are frequent. When demand is normalised by TRV instead of gross residential volume, volumetric intensities increase systematically, especially in metropolitan provinces. In other words, the same residential electricity demand is concentrated in a slightly smaller, more realistic residential volume.

This has two implications. First, it suggests that using gross residential volume in dense mixed-use contexts underestimates the effective load density experienced by dwellings that are actually on domestic contracts. Second, it also shows the limits of the current data: the TRV correction can only be applied in Piedmont, where mixed-use labels and volume information are available. Lazio and Sicily remain on gross residential volume, and this asymmetry has to be kept in mind when comparing intensities across regions.

6.3 Residential demand patterns in a north–centre–south transect

Combining the building indicators with ARERA provincial demand data produces a more nuanced picture of residential demand than national-level statistics.

At annual scale, demand per household falls in a relatively narrow band across the three regions but shows a clear gradient: Piedmont tends to have lower values, Lazio sits in the middle, and several Sicilian provinces are at the higher end. Part of this can be linked to climate (cooling loads in southern coastal provinces), but it also reflects differences in dwelling size, equipment and occupancy.

When expressed per unit of residential volume, metropolitan provinces such as Torino and Roma show higher volumetric intensities, especially when TRV is used in Piedmont. This is coherent with the idea that households in large cities tend to live in smaller dwellings, often in multi-storey buildings, so that similar absolute demand is concentrated in less cubic metres.

Hourly profiles for Torino, Roma and Catania add a temporal dimension. All three provinces show clear evening peaks, but summer afternoon and evening loads are much more pronounced in Roma and especially in Catania, reflecting the stronger role of cooling in central and southern climates. The simple peak-to-valley ratios confirm that intra-day variability is slightly higher in Roma and Catania than in Torino. These indicators are simple, but they are enough to show that "residential demand" does not have a single shape across Italy: it changes with both climate and the structure of the building stock.

Overall, the residential indicators do not form a full bottom-up demand model, but they already allow a basic differentiation between types of territories: dense mixed-use cores with high volumetric intensity and marked evening peaks; suburban or small-town areas with lower intensities; and southern contexts where cooling significantly reshapes the daily profile.

6.4 Implications for REC-oriented planning

Even without running REC simulations, the results have direct implications for REC-oriented planning and more general energy policies.

On the spatial side, the hybrid classification provides a quick way to see where residential, service, industrial and primary-sector buildings are located and how they overlap. This is exactly the type of information needed to identify potential REC catchment areas: clusters of residential buildings around a school, a supermarket, a municipal building or an industrial site that could act as an anchor load.

On the quantitative side, the residential indicators and sectoral comparisons give a first idea of what to expect in different contexts:

- provinces with higher kWh per household and higher volumetric intensities may be more sensitive to changes in tariffs or efficiency measures.
- provinces with higher peak-to-valley ratios will face greater challenges in matching residential demand with local PV generation and may need more flexibility or storage.
- in all three regions, service buildings emerge as highly electricity-intensive per unit of volume, even when their share of total volume is modest.

Taking together, these results suggest that REC policies should not focus only on purely residential districts. Mixed-use areas where RL/RM buildings coexist with service and industrial stock may offer better opportunities for balancing generation and demand, because non-residential users provide more stable daytime loads that can complement residential evening peaks. The hybrid classification and the TRV concept do not solve REC design by themselves, but they offer a consistent, spatially explicit starting point for deciding where REC initiatives are more likely to be technically meaningful and socially relevant.

7. Conclusion

This thesis set out to build and test an energy-oriented, hybrid classification of the Italian building stock in three regions – Piedmont, Lazio and Sicily – and to link it with simple but spatially explicit indicators of residential electricity demand. The work stayed deliberately close to the available data: regional technical maps with detailed *uso* fields, census information on population and households, and provincial residential electricity statistics from ARERA and RAEE. Within this framework, the thesis treated the residential sector as the main focus, while keeping non-residential uses in the picture as context and potential anchor loads for REC-oriented planning.

7.1 Summary of Contributions

This thesis has shown that three different regional technical maps can be brought into a single, energy-oriented framework. By translating the original *uso* fields into a small set of hybrid classes (RL, RM, PA, SP, TC, TH, TT, Others), it becomes possible to read Piedmont, Lazio and Sicily through the same lens and to compare their building stocks without losing the basic meaning of the regional categories. The resulting maps give a coherent picture of how residential, industrial, service and primary buildings are distributed in a northern, central and a southern region.

The work also refines how the residential stock is described. Aggregating residential buildings by province and expressing them in terms of volume per inhabitant and per household helps to distinguish metropolitan provinces with compact dwellings from more rural or small-town areas with more space per household. In Piedmont, the explicit treatment of mixed-use residential buildings and the definition of True Residential Volume (TRV) add an extra step, by separating nominal residential volume from the portion of volume that is more likely to be linked to domestic electricity contracts.

Finally, the thesis links this spatial information with provincial electricity data. Combining ARERA's annual and hourly demand for domestic users with residential volumes (gross and TRV-based) produces a set of simple intensity indicators that vary across provinces and follow a clear north–center–south gradient. The sectoral comparison between RAEE electricity statistics and hybrid-class building volumes confirms that service buildings concentrate a large share of electricity use in all three regions, even where their share of volume is modest. Together, these elements provide a concise, spatially explicit way to read residential electricity demand and its relationship with the wider building stock.

7.2 Reflections on the research questions

The starting questions of the thesis were whether a hybrid, energy-oriented classification could be applied consistently to different regional technical maps; whether it could improve the way residential demand is read from provincial statistics; and whether it could provide information that is meaningful for REC-oriented planning.

The results suggest that the answer is broadly positive, within the limits of the available data. The hybrid classification works across the three case-study regions and reproduces a plausible geography of residential, industrial, tertiary and primary uses. The introduction of TRV in Piedmont refines the notion of "residential volume" in mixed-use contexts and leads to more conservative but more realistic volumetric intensities in metropolitan provinces. The combination of building indicators with ARERA data produces a differentiated picture of residential demand, where provinces are no longer just points on a national average line but territories with their own stock structure and load shapes.

At the same time, the thesis remains intentionally modest in its claims. The indicators constructed here do not amount to a full bottom-up demand model and do not capture the full diversity of households, technologies and behaviours. They are, however, consistent with the main signals coming from sectoral statistics and empirical load-profile studies, and they show that even relatively simple combinations of spatial and energy data can already support a more place-based reading of residential electricity use.

7.3 Final Takeaways for Planners and Policymakers

The results of this thesis underline a very simple message: the quality and granularity of basic building-stock information matter a lot for energy planning. Regional technical maps, *uso* fields and height or volume attributes are not just cartographic details; they strongly condition what can be said about residential demand, mixed-use neighbourhoods and the role of different sectors in electricity use. Where the original database distinguishes mixed uses and provides volume information, as in Piedmont, it becomes possible to refine the notion of “residential volume” through indicators such as TRV and to build intensity metrics that are more consistent with how domestic contracts are actually defined. Where *uso* labels are generic, as in parts of Sicily, the analysis must stay at a coarser level and important nuances are inevitably lost.

For planners and policymakers, this has two immediate implications. Reading provincial electricity statistics or national sectoral balances without considering how buildings are actually mapped on the ground can lead to misleading conclusions. The same annual kWh per household can correspond to very different volumetric intensities, depending on dwelling size and mixed-use patterns, and the same share of “residential” electricity in RAEE can sit on top of very different combinations of residential, tertiary and industrial buildings. Investing in clearer, more standardised *uso* categories, and in regular maintenance of regional building databases, is therefore not a technical luxury but a prerequisite for robust local energy strategies.

At the same time, the thesis suggests that even simple improvements can go a long way. Making mixed-use labels explicit, recording basic height information, and ensuring that regional technical maps are accessible and harmonised across regions would already allow a more consistent link between spatial planning tools and energy data. For REC policy in particular, having a hybrid, energy-oriented view of the building stock makes it easier to see where residential users are concentrated, where high-intensity service or industrial loads are located, and where their interaction could be most productive. If future updates of regional databases keep this perspective in mind, planners will be better equipped to design interventions that are both technically sound and sensitive to the specific structure of each territory, rather than relying on uniform national averages.

References

Alberini, A., Prettico, G., Shen, C., & Torriti, J. (2019). Hot weather and residential hourly electricity demand in Italy. Energy, 177, 44–56. https://doi.org/10.1016/j.energy.2019.04.051

Almeida, M. T. P. (2013). Analyzing Residential Electricity Consumption Patterns Based on Consumer's Segmentation [Master's thesis, Instituto Superior Técnico, Universidade Técnica de Lisboa].

Ao, J., Du, C., Jing, M., Li, B., & Chen, Z. (2024). A method of integrating air conditioning usage models to building simulations for predicting residential cooling energy consumption. Buildings, 14(7), 2026. https://doi.org/10.3390/buildings14072026

ARERA (Autorità di Regolazione per Energia Reti e Ambiente). (n.d.). Analisi dei consumi dei clienti domestici. Retrieved June 8, 2025, from https://www.arera.it/dati-e-statistiche/dettaglio/analisi-dei-consumi-dei-clienti-domestici

ENEA. (2024). *Rapporto Annuale sull'Efficienza Energetica 2024 – Schede Regionali*. Retrieved from *https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-efficienza-energetica-2024-schede-regionali.html*

Aruta, G., Ascione, F., Fistola, R., & Iovane, T. (2024). The city as a power hub for boosting renewable energy communities: A case study in naples. Sustainability, 16(18), 7988. https://doi.org/10.3390/su16187988

Azzolini, G., Hugony, F., & Martino, A. (2020). Implementation of the EPBD: Italy Status in 2020. Concerted Action Energy Performance of Buildings. ENEA & CTI.

Ballarini, I., & Corrado, V. (2017). A new methodology for assessing the energy consumption of building stocks. Energies, 10(8), 1102. https://doi.org/10.3390/en10081102

Besagni, G., Vilà, L. P., & Borgarello, M. (2020). Italian household load profiles: A monitoring campaign. Buildings, 10(12), 217. https://doi.org/10.3390/buildings10120217

Bianco, G., Bonvini, B., Bracco, S., Delfino, F., Laiolo, P., & Piazza, G. (2021). Key performance indicators for an energy community based on sustainable technologies. Sustainability, 13(16), 8789. https://doi.org/10.3390/su13168789

Brunelli, C., Genovese, A., & Sasso, M. (2025). Design methodology of a multi-source renewable energy community. Energy, 287, 132034. https://doi.org/10.1016/j.energy.2024.132034

Caferra, R., D'Adamo, I., & Gastaldi, M. (2024). Renewable energy communities in Italy: A strategic analysis. Energy Strategy Reviews, 52, 101297. https://doi.org/10.1016/j.esr.2024.101297

Carvalho, T. R., Soares, J., Lopes, M., Gomes, L., & Vale, Z. (2025). A non-cooperative game theory approach for sharing schemes analysis in energy communities. International Journal of Electrical Power & Energy Systems, 165, 109968. https://doi.org/10.1016/j.ijepes.2024.109968

Chen, L., Zheng, Y., Yu, J., Peng, Y., Li, R., & Han, S. (2024). A GIS-based approach for urban building energy modeling under climate change with high spatial and temporal resolution. Energies, 17(17), 4313. https://doi.org/10.3390/en17174313

Conticelli, E., Tondelli, S., & Callegari, G. (2024). A simplified methodology for the energy performance upscaling of existing residential buildings at the urban scale. Buildings, 14(4), 1014. https://doi.org/10.3390/buildings14041014

D'Amico, A., Ciulla, G., & Panno, D. (2020). Data-driven building archetyping: A review. Energy and Buildings, 228, 110433. https://doi.org/10.1016/j.enbuild.2020.110433

Delmastro, C., Mutani, G., & Schranz, L. (2015). The evaluation of buildings energy consumption and the optimization of district heating networks: A GIS-based model. International Journal of Energy and Environmental Engineering, 7(3), 343–351. https://doi.org/10.1007/s40095-015-0161-5

Delzendeh, E., Wu, S., Lee, A., & Zhou, Y. (2017). A review on the impact of occupant behavior on building energy consumption. Energy and Buildings, 148, 94-106. https://doi.org/10.1016/j.enbuild.2017.08.042

ENEA. (2024). Rapporto Annuale sull'Efficienza Energetica 2024. Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile.

European Commission. (2024). Final updated National Energy and Climate Plan 2021-2030 (Italy). Retrieved from https://commission.europa.eu/publications/italy-final-updated-necp-2021-2030-submitted-2024_en

European Parliament and Council of the European Union. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (RED II). Official Journal of the European Union, L 328/82.

European Parliament and Council of the European Union. (2023). Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001... (RED III). Official Journal of the European Union, L 2023/2413.

Fabi, V., Andersen, R. K., Corgnati, S., & Olesen, B. W. (2017). The role of occupant behavior in building energy performance: A review. Energy and Buildings, 149, 279-293. https://doi.org/10.1016/j.enbuild.2017.05.014

Gaetani, I., Hoes, P.-J., & Hensen, J. L. M. (2016). On the sensitivity to different aspects of occupant behaviour for selecting the appropriate modelling complexity in building performance predictions. Journal of Building Performance Simulation, 10(5–6), 601–611. https://doi.org/10.1080/19401493.2016.1260159

García-López, J., Sendra, J. J., & Domínguez-Amarillo, S. (2024). Validating "GIS-UBEM"—a residential open data-driven urban building energy model. Sustainability, 16(6), 2599. https://doi.org/10.3390/su16062599

Glazar, V., Kunič, R., & Krainer, A. (2023). Archetype identification in Urban Building Energy Modeling: Problems, methods, and decision-making. Energy and Buildings, 296, 113359. https://doi.org/10.1016/j.enbuild.2023.113359

GSE. (2024a, January). Energia da fonti rinnovabili in Italia nel 2023: Rapporto Statistico. Gestore dei Servizi Energetici.

GSE. (2024b, May). Solare Fotovoltaico - Rapporto Statistico 2023. Gestore dei Servizi Energetici.

Hakawati, B., Mousa, A., & Draidi, F. (2024). Smart energy management in residential buildings: The impact of knowledge and behavior. Scientific Reports, 14(1), 1085. https://doi.org/10.1038/s41598-024-51638-y

Hertwig, D., McGrory, M., Paskin, M., Liu, Y., Piano, S. L., Llanwarne, H., Smith, S. T., & Grimmond, S. (2025). Connecting physical and socio-economic spaces for multi-scale urban modelling: A dataset for london. Geoscience Data Journal, 12(2). https://doi.org/10.1002/gdj3.289

Hong, T. (2017). A critical review of Urban Building Energy Modeling. Energy and Buildings, 152, 370-371. https://doi.org/10.1016/j.enbuild.2017.04.013

Hong, T., & Yan, D. (2019). Future research directions in building energy modeling. Energy and Buildings, 183, 783-791. https://doi.org/10.1016/j.enbuild.2018.11.026

Huang, X., Hayashi, K., Matsumoto, T., Tao, L., Huang, Y., & Tomino, Y. (2022). Estimation of rooftop solar power potential by comparing solar radiation data and remote sensing data—a case study in aichi, japan. Remote Sensing, 14(7), 1742. https://doi.org/10.3390/rs14071742

Johari, F., Shadram, F., & Widén, J. (2023). Urban building energy modeling from geo-referenced energy performance certificate data: Development, calibration, and validation. Sustainable Cities and Society, 96, 104664. https://doi.org/10.1016/j.scs.2023.104664

Kontokosta, C. E., & Tull, C. (2017). The impact of data granularity on building energy benchmarking. Applied Energy, 198, 268-281. https://doi.org/10.1016/j.apenergy.2017.04.041

Lee, S., Lee, B. D., & Kim, H. G. (2018). Impact of the surrounding built environment on energy consumption in mixed-use building. Sustainability, 10(3), 856. https://doi.org/10.3390/su10030856

Leprince, J., Schledorn, A., Guericke, D., Dominkovic, D. F., Madsen, H., & Zeiler, W. (2023). Can occupant behaviors affect urban energy planning? Distributed stochastic optimization for energy communities. arXiv. https://doi.org/10.48550/ARXIV.2303.03006

Long, C., Wu, J., Zhang, C., Thomas, L., Cheng, M., & Jenkins, N. (2021). Modeling and simulation of energy communities: A review. Renewable and Sustainable Energy Reviews, 138, 110463. https://doi.org/10.1016/j.rser.2020.110463

Lopez, M., Rodriguez-Donate, C., & Echarri, V. (2021). Accurate prediction of hourly energy consumption in a residential building based on the occupancy rate using machine learning approaches. Applied Sciences, 11(5), 2229. https://doi.org/10.3390/app11052229

Mancini, F., & Nastasi, B. (2020). Solar energy data analytics: PV deployment and land use. Energies, 13(2), 417. https://doi.org/10.3390/en13020417

Massimo, A., Dell'Isola, M., Frattolillo, A., & Ficco, G. (2014). Development of a geographical information system (GIS) for the integration of solar energy in the energy planning of a wide area. Sustainability, 6(9), 5730–5744. https://doi.org/10.3390/su6095730

Ministero dell'Ambiente e della Sicurezza Energetica (MASE). (2023). Decreto Ministeriale n. 414 del 7 dicembre 2023. [Ministerial Decree].

Mutani, G., Morando, V., Zhou, X., Tayefinasrabad, M., & Tundo, A. (2024). An Italian Geoportal for Renewable Energy Communities. Journal of Sustainability for Energy, 3(4), 244–264. https://doi.org/10.56578/jse030404

Mutani, G., Santantonio, S., & Foliente, G. (2020). Geospatial data analysis to assess the impact of energy efficiency measures for the requalification of existing buildings. Energy Procedia, 180, 900–909. https://doi.org/10.1016/j.egypro.2020.06.089

Mutani, G., & Todeschi, V. (2021). Optimization of Costs and Self-Sufficiency for Roofs-Integrated Photovoltaic Panels in Energy Community Districts. Energies, 14(20), 6598. https://doi.org/10.3390/en14206598

Mutani, G., Todeschi, V., & Fregonara, E. (2023). A statistical energy model for residential building stock by means of EPC data and GIS tools: The case study of

Milan. Energy and Buildings, 296, 113337. [*https://doi.org/10.1016/j.enbuild.2023.113337*](https://doi.org/10.1016/j.enbuild.2023.113337)

NREL. (2021). End-Use Load Profiles for the U.S. Building Stock. National Renewable Energy Laboratory. Retrieved from [*https://www.nrel.gov/buildings/end-use-load-profiles.html*](https://www.nrel.gov/buildings/end-use-load-profiles.html)

NREL. (n.d.-a). ComStock. Retrieved June 8, 2025, from [*https://www.nrel.gov/buildings/comstock.html*](https://www.nrel.gov/buildings/comstock.html)

NREL. (n.d.-b). URBANopt. Retrieved June 8, 2025, from [*https://www.nrel.gov/buildings/urbanopt.html*](https://www.nrel.gov/buildings/urbanopt.html)

Parra, D., Norman, S. A., Walker, G. S., & Gillott, M. (2017). Optimum community energy storage for renewable energy and demand load management. Applied Energy, 200, 358-369. [*https://doi.org/10.1016/j.apenergy.2017.05.049*](https://doi.org/10.1016/j.apenergy.2017.05.049)

Pellegrino, A., Ciuffo, B., & Realini, A. (2023). Energy performance gap in residential buildings: Comparing asset rating calculations with actual energy consumption. Sustainability, 15(4), 3647. [*https://doi.org/10.3390/su15043647*](https://doi.org/10.3390/su15043647)

Poggi, F., & Amado, M. (2024). The spatial dimension of energy consumption in cities. Energy Policy, 187, 114023. [*https://doi.org/10.1016/j.enpol.2024.114023*](https://doi.org/10.1016/j.enpol.2024.114023)

Rane, N. L., Günen, M. A., Mallick, S. K., Rane, J., Pande, C. B., Giduturi, M., Bhutto, J. K., Yadav, K. K., Tolche, A. D., & Alreshidi, M. A. (2024). GIS-based multi-influencing factor (MIF) application for optimal site selection of solar photovoltaic power plant in nashik, india. Environmental Sciences Europe, 36(1), 22. [*https://doi.org/10.1186/s12302-023-00832-2*](https://doi.org/10.1186/s12302-023-00832-2)

Reinhart, C. F., & Davila, C. C. (2016). Urban building energy modeling: A review of a nascent field. Building and Environment, 97, 196-202. [*https://doi.org/10.1016/j.buildenv.2015.12.001*](https://doi.org/10.1016/j.buildenv.2015.12.001)

Resch, B., Sagl, G., Törnros, T., Bachmaier, A., Eggers, J.-B., Herkel, S., Narmsara, S., & Gündra, H. (2014). GIS-based planning and modeling for renewable energy: Challenges and future research avenues. ISPRS International Journal of Geo-Information, 3(2), 662–692. [*https://doi.org/10.3390/ijgi3020662*](https://doi.org/10.3390/ijgi3020662)

Saltamerenda, L., Chiesa, G., & Fregonara, E. (2024). Comparative analysis of urban building energy modeling tools: A case study in Torino, Italy. Applied Sciences, 14(10), 2618. [*https://doi.org/10.3390/app14102618*](https://doi.org/10.3390/app14102618)

Saretta, E., Caputo, P., & Chiesa, G. (2021). The role of building energy modeling in the design of positive energy districts. Sustainable Cities and Society, 75, 103239. [*https://doi.org/10.1016/j.scs.2021.103239*](https://doi.org/10.1016/j.scs.2021.103239)

Sark, A. K., Grueneis, H., Khadka, A., Svidritskiy, E., Sokol, J., Hauer, S., Knoeri, C., Mastrucci, A., Kienberger, T., Müller, D. B., & Mavromatidis, G. (2023). Spatio-temporal building typologies for urban energy modelling. Applied Energy, 339, 120823. https://doi.org/10.1016/j.apenergy.2023.120823

Sola, A., Corchero, C., Salom, J., & Sanmarti, M. (2018). A review of data sources for urban building energy modeling. Energy and Buildings, 175, 74-87. https://doi.org/10.1016/j.enbuild.2018.06.046

Swinter. (2024, March 17). The Role of TEDI in Building Energy Codes. Retrieved June 8, 2025, from https://www.swinter.com/role-of-tedi-in-building-energy-codes/

Taylor, Z. T., Gowri, K., & K. K. (2008). GridLAB-D Technical Support Document: Residential End-Use and Thermostat Models. (PNNL-17694). Pacific Northwest National Laboratory.

Vecchi, F., Cagni, A., & Barchi, G. (2024). Assessment Models and Tools for Renewable Energy Communities: A Comparative Review. Energies, 17(5), 1145. https://doi.org/10.3390/en17051145

Wei, Y., Zhang, X., Shi, Y., Xia, L., Pan, S., Wu, J., Han, M., & Zhao, X. (2018). Hybrid building energy modeling: A review of data-driven and physics-based approaches. Renewable and Sustainable Energy Reviews, 82, 3000-3010. https://doi.org/10.1016/j.rser.2017.05.084

Wilson, E., Parker, A., Horowitz, K., & Sparn, B. (2022). ResStock Analysis: U.S. Residential Building Stock Energy Consumption and Saving Potential (Technical Report NREL/TP-5500-83077). National Renewable Energy Laboratory.

Yan, D., Hong, T., Dong, B., Mahdavi, A., D'Oca, S., Gaetani, I., & Feng, X. (2017). Occupant behavior and energy consumption in buildings: A review. Energy and Buildings, 150, 243-257. https://doi.org/10.1016/j.enbuild.2017.03.011

Appendices

Classification keyword dictionaries

Piemonte

EDIFC_USO	CLASSIFICA
Non conosciuto	Others
Non definito	Others
altro	Others
campeggio	TC
eliporto	Others
stazione di telecomunicazioni	SP
stazione di telecomunicazioni	SP
agriculturale	PA
allevamento	PA
fattoria	PA
fienile	PA
stalla	PA
abitativa	RL
residenziale	RL
residenziale e agricolo	RM
residenziale e commerciale	RM
residenziale e produttivo	RM
residenziale e ricreativo	RM
residenziale e ufficio pubblico	RM
centrale elettrica	SP
depuratore	SP
impianto di produzione energia	SP
inceneritore	SP
industriale	SP
stabilimento industriale	SP
amministrativo	TC
biblioteca	TC
carcere, istituto di pena	TC
casello forestale	TC
caserma	TC
commerciale	TC
convento	TC
laboratorio di ricerca	TC
luogo di culto	TC
mercato	TC
militare	TC
municipio	TC
museo	TC
palestra	TC
piscina coperta	TC
rifornimento carburanti	TC

rifugio montano	TC
sanitÃ	TH
sede albergo, locanda	TC
sede clinica	TH
sede di attivitÃ culturali	TC
sede di attivitÃ sportive	TC
sede di banca	TC
sede di centro commerciale	TC
sede di citta' metropolitana	TC
sede di forze dell'ordine	TC
sede di poste-telegrafi	TC
sede di servizio socio assistenziale	TC
sede di supermercato, ipermercato	TC
sede di tribunale	TC
sede di vigili del fuoco	TC
sede provincia	TC
sede regione	TC
sede servizi sanitari asl	TH
servizio pubblico	TC
struttura alberghiera	TC
strutture ricettive	TC
uso misto di altro tipo	TC
sede di ospedale	TH
cinema	TI
ricreativo	TI
teatro, auditorium	TI
istruzione	TS
sede di scuola	TS
universitÃ	TS
aereo	TT
altro impianto di trasporto	TT
deposito ferroviario per vagoni, rimessa locomotive	TT
edificio accessorio alle strade	TT
ferroviario	TT
parcheggio multipiano o coperto	TT
servizi di trasporto	TT
stazione autolinee	TT
stazione cabinovia	TT
stazione funivia	TT
stazione marittima	TT
stazione passeggeri aeroportuale	TT
stazione passeggeri ferroviaria	TT
stazione seggiovia	TT
stazione skilift	TT
stradale	TT

Lazio

Uso_Code_Text	Uso_Label	CLASSIFICA
edifici		
'01	residenziale	RL
'0101	abitativa	RL
'02	amministrativo	TC
'0201	municipio	TC
'0202	sede provincia	TC
'0203	sede regione	TC
'0204	sede ambasciata o consolato	TC
'0205	sede di città metropolitana	TC
'03	servizio pubblico	TC
'0301	sanità	TH
'030101	sede di servizio socio assistenziale	TC
'030102	sede di ospedale	TH
'030103	sede servizi sanitari asl	TC
'030104	sede clinica	TH
'0303	istruzione	TS
'030301	sede di scuola	TS
'030302	università	TS
'030303	laboratorio di ricerca	TS
'0304	sede di poste-telegrafi	TC
'0305	sede di tribunale	TC
'0306	sede di forze dell'ordine	TC
'0307	sede di vigili del fuoco	TC
'0308	casello forestale	TC
'04	militare	TC
'0401	caserma	TC
'05	luogo di culto	TC
'0501	convento	TC
'06	servizi di trasporto	TT
'0601	aereo	TT
'060101	stazione passeggeri aeroportuale	TT
'060102	eliporto	TT
'0602	stradale	TT
'060201	stazione autolinee	TT
'060202	parcheggio multipiano o coperto	TT
'060203	edificio accessorio alle strade	TT
'0603	ferroviario	TT
'060301	stazione passeggeri ferroviaria	TT
'060302	deposito ferroviario per vagoni, rimessa locomotive	TT
'060303	casello ferroviario	TT
'060304	fermata ferroviaria	TT
'060305	scalo merci	TT
'0604	altro impianto di trasporto	TT
'060401	stazione marittima	TT
'060402	stazione metropolitana	TT
'060403	stazione tranviaria	TT

'060404	stazione funivia	TT
'060405	stazione cabinovia	TT
'060406	stazione seggiovia	TT
'060407	stazione skilift	TT
'07	commerciale	TC
'0701	sede di banca	TC
'0702	sede di centro commerciale	TC
'0703	mercato	TC
'0704	sede di supermercato, ipermercato	TC
'08	industriale	SP
'0801	stabilimento industriale	SP
'0802	impianto di produzione energia	SP
'080201	centrale elettrica	SP
'080202	centrale termoelettrica	SP
'080203	centrale idroelettrica	SP
'080204	centrale nucleare	SP
'080206	stazione di trasformazione	SP
'0803	impianto tecnologico	SP
'0804	depuratore	SP
'0805	inceneritore	SP
'0806	stazione di telecomunicazioni	SP
'0807	edificio di teleriscaldamento	SP
'0808	edificio di area ecologica	RL
'09	agricolturale	PA
'0901	fattoria	PA
'0902	stalla	PA
'0903	fienile	PA
'0904	allevamento	PA
'10	ricreativo	TI
'1001	sede di attività culturali	TS
'100101	biblioteca	TS
'100102	cinema	TI
'100103	teatro, auditorium	TI
'100104	museo	TC
'100105	pinacoteca	TC
'1002	sede di attività sportive	TC
'100201	piscina coperta	TC
'100202	palestra	TC
'100203	palaghiaccio	TI
'11	carcere, istituto di pena	TC
'12	strutture ricettive	TC
'1201	struttura alberghiera	TC
'1202	sede albergo, locanda	TC
'1203	campeggio	TC
'1204	rifugio montano	TC
'95	altro	Others
industriali		
'01	cabina trasformazione energia	SP

'02	cabina rete acqua	SP
'03	cabina rete gas	SP
'04	aeromotore	SP
'05	torre di raffreddamento	SP
'06	ciminiera	Others
'07	contenitore industriale protetto	Others
'0701	cisterna	Others
'0702	serbatoio	Others
'070201	serbatoio interrato	Others
'070202	serbatoio in superficie	Others
'070203	serbatoio pensile	Others
'0703	silo	Others
'08	manufatti di impianti produzione energia	SP
'0801	pala eolica	SP
'0802	pannello fotovoltaico	SP
'0803	pannello solare	SP
'09	pozzo captazione/stazione di pompaggio	SP
'10	forno	SP
'11	vasca	Others
'12	torre piezometrica	Others
'13	serra	SP
'14	idrovora	SP
'15	abbeveratoio	Others
'95	altro	Others

Sicilia

Baracca	**R**
Centrale elettrica, cabina elettrica	SP
Chiesa, campanile	TC
Edificio civile, sociale, amministrativo	R
Edificio in costruzione	Others
Serra stabile	PA
Stabilimento industriale, capannone, edificio commerciale	SP
Stalla, fienile	PA
Tendone pressurizzato	TC
Tettoia, pensilina	Others
Torre, ciminiera, silos	Others