Mispricing Energy Efficiency? Discrete Labels, Continuous Performance, and Policy Gaps in Urban Housing Markets

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Abstract. Energy Performance Certificates (EPCs) have been designed to overcome information asymmetries in housing markets, making the energy efficiency of homes an observable and comparable property characteristic. However, the energy classes used by EPCs can influence housing prices in ways that go beyond the underlying level of energy performance itself. This paper investigates whether the market valuation of energy efficiency follows the logic of energy consumption or the structure of EPC classes as discrete labels. Using listing data from six urban housing markets in the Veneto region (Italy), we estimate city-specific hedonic price models with spatial controls under two alternative representations of energy efficiency: a categorical one, based on EPC class dummies, and a continuous one, derived from representative values of non-renewable primary energy consumption. Results show that energy efficiency positively impacts housing prices, but capitalization patterns differ across markets and model specifications. While in some cities price premiums change smoothly along the EPC ladder and largely correspond to the energy performance gradient, in other cities thresholds, discontinuities, and non-monotonicity can be detected. These findings suggest that the representation of energy efficiency is not merely a modeling choice, but a substantive issue for both empirical analysis and policy design.

Keywords: Energy efficiency · Green premium · Housing markets

1 Introduction

The transition of the residential building stock towards better energy efficiency (EE) represents one of the key challenges in modern environmental and urban

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O. Gervasi et al. (Eds.): ICCSA 2026 Workshops, LNCS 16764, pp. 3–20, 2027.
https://doi.org/10.1007/978-3-032-30533-6_1

policy. In the European Union, buildings account for around 40% of total energy consumption and 36% of greenhouse gas emissions, making improvements in building efficiency a key pillar of decarbonization strategies. The long durability of buildings and their slow adaptation make EE not only an environmental issue but an economic one as well, with direct consequences for households and investors and important implications for the Real Estate (RE) market dynamics. A series of amendments to the Energy Performance of Buildings Directive (EPBD) contributed to further strengthening the regulatory and information-based system for managing building efficiency. One of the central instruments introduced through the EPBDs is the Energy Performance Certificate (EPC), which provides a standardized measure of EE through a publicly disclosed classification system. The introduction of such a certificate is intended to reduce the problem of information asymmetry and allow market participants to incorporate EE information into property valuation.

From a theoretical point of view, the relationship between EE and housing prices should reflect the net present value of future cost savings: dwellings with higher EE require less energy to produce the same amount of housing services, generating a stream of benefits that should be capitalized into property prices. Thus, the relationship between housing prices and EE should be monotonic and proportional to the expected level of savings. Empirically, however, this relationship appears difficult to detect due to high uncertainty concerning the parameters needed to estimate expected savings, in particular consumption patterns, current and future energy prices, and discount rates. For this reason, empirical studies typically rely on a physical measure of energy performance (mostly energy consumption or energy performance index) as a proxy for the future stream of energy savings. However, market participants rarely observe or process energy information in this form. In practice, they encounter EE primarily through EPC labels. Such a representation implies that labels correspond to intervals of performance rather than to precise values, and these intervals are not equally spaced along the energy scale. Identical transitions between adjacent classes therefore do not correspond to uniform changes in underlying consumption. The informational structure conveyed by EPCs is thus inherently discrete and non-linear. As a result, housing prices may respond more strongly to label membership than to the continuous gradient of energy performance itself.

This issue is relevant not only from an economic perspective but also from a policy one, since it concerns not only whether EE is capitalized in housing prices but also whether this capitalization is consistent with the underlying energy performance gradient. If prices respond disproportionately to discrete labels, the resulting market signals may deviate from the actual distribution of expected energy savings. Such deviations may reflect bounded rationality, informational frictions, or the fact that EPC labels also act as broader signals of housing quality. From a policy perspective, this matters because EPCs are intended to support efficient choices by improving transparency. When market responses are influenced by simplified signals such as labels, however, policy design becomes more complex and may require structured decision-support approaches capable

of integrating multiple dimensions and stakeholders' preferences. In this context, multicriteria methods have been proposed as useful tools to support the design of energy policies and incentive schemes [1–4].

This paper addresses the identified issue by comparing two alternative representations of energy performance. The first approach uses categorical EPC classes as explanatory variables to capture the discrete, label-based structure through which energy information is disclosed in the market. The second approach relies on a linear relationship that uses the non-renewable primary energy consumption associated with each class as an explanatory variable, providing a benchmark consistent with a proportional valuation of energy performance. The comparison is conducted across six local housing markets in the Veneto region, allowing capitalization patterns to vary across cities. By contrasting the price schedules implied by the two specifications, the study examines whether the observed structure of energy premiums is aligned with the underlying consumption gradient or instead reflects discontinuous and uneven responses to EPC labels.

The remainder of the paper is organized as follows. The literature review is presented in Sect. 2, where special attention is paid to alternative ways to represent energy performance in RE models. Section 3 presents the methodological approach and the econometric models. Section 4 describes the case study and the dataset. Section 5 discusses the empirical findings and compares the capitalization pattern generated by the two alternative approaches. Section 6 concludes.

2 Literature Review

In the past two decades, the widespread adoption of EPCs in residential markets has helped establish EE as an explicit property attribute, making it a well-studied topic in RE. With a rapidly growing body of literature on the topic, one broad empirical regularity has become increasingly clear: energy-efficient houses tend to be priced above otherwise comparable properties. This regularity is typically referred to as the "green premium". Nonetheless, the literature is marked by considerable diversity in the estimated effects and methodological inconsistencies. An important aspect of this heterogeneity pertains to the way energy performance is operationalized in models. Specifically, three main strategies can be identified.

The first specification involves modeling energy performance as a continuous variable. Such measures may include, among others, energy consumption, energy expenditure, or synthetic performance indices. From the perspective of economic theory, this strategy is the most intuitive, since it preserves the physical dimension of energy consumption and implies that price effects scale proportionally with potential savings. Empirical evidence broadly supports this interpretation. In the United States, a 1% decrease in energy expenditure per square meter has been associated with an increase of about 2% in the self-reported house value [5]. Similarly, positive effects are estimated in European housing markets. For instance, a 10% improvement in a continuous energy performance index

is associated with an increase of around 2.2% in prices in the Dutch housing market [6], while in Sweden a 1% drop in energy consumption relates to a 0.4% growth in transaction prices [7]. In Germany, a decrease of 100 kWh/m^2 in energy consumption is associated with a 6.9% price premium [8], and a 1% increase in the energy performance score is associated with a 0.11% increase in price [9].

The second strategy treats energy performance as a set of distinct EPC classes that serve as categorical independent variables, each receiving a dedicated coefficient and thus producing a flexible price schedule. This specification closely resembles the way in which energy performance is communicated to market participants through distinct classes or labels rather than through consumption values. However, in practice, this strategy often results in irregular premiums concentrated at top-rated classes, with limited statistical significance at intermediate levels. This pattern emerges, for example, in Barcelona, where only certain EPC classes have a significant impact on price and there is substantial heterogeneity in the effects observed across different market segments [10]. In Alicante, evidence suggests that the absence of information disclosure may work in favor of less efficient houses, which trade close to more efficient properties [11].

Some researchers adopt an intermediate approach by representing EPC classes as numeric or ordinal variables, assigning, for instance, values from 1 (class G) to 7 (class A) and estimating a single linear effect [12–15]. While this strategy is concise and preserves the ordering of energy performance, it implies strong assumptions: all classes are equally spaced in terms of energy consumption and the price premium associated with moving from one class to the next is constant. As a result, the estimate should be interpreted as an average gradient that is likely to conceal possible discontinuities, threshold effects, and non-linearity.

Finally, a limited but especially valuable set of studies compares continuous and categorical representations within a consistent framework. These contributions are particularly important because the two representations cannot be regarded simply as different codings of the same information. Indeed, when applied in the Belfast housing market, both strategies result in positive premiums, although the categorical specification reveals more pronounced differences across market segments [16]. Similar patterns have been found in Dublin and in the England and Wales housing markets, with energy scores and EPC classes showing comparable but not identical patterns [17,18]. These findings suggest that continuous and categorical models may capture somewhat different facets of market behavior. However, a systematic, in-depth comparison of the two approaches across local markets within a single empirical setup is still relatively uncommon. In the vast majority of cases, researchers view them as alternative methods and do not test whether categorical price schedules are consistent with the corresponding continuous energy performance gradient. As a result, the literature still lacks a systematic assessment of the discrepancy between the two strategies. This argument is further supported by recent regression discontinuity evidence. Studying the French housing market, Lu and Spaenjers [19] document significant discontinuities in the estimated price premiums at every threshold between consecutive classes, despite smooth changes in underlying energy con-

sumption. Estimated discontinuities range between 1.9% and 4.5%, indicating that the label itself adds an effect beyond the continuous measure of energy performance. This finding suggests that market valuations may depend on EPC classes not just as a proxy for EE but as salient informational labels. Consistent behavioral evidence in this context shows that many households have poor understanding of EPCs and interpret energy classes as quality ratings rather than as precise indicators of future energy consumption [20].

Overall, the literature highlights an important inconsistency in current understanding. Continuous representations are more consistent with economic theory and assume a proportional relationship between prices and the energy performance gradient, while categorical ones better reflect the way information is communicated in the market but lead to irregular premium distributions and sometimes discontinuous pricing patterns. These two specifications reflect distinct ways in which information processing takes place: continuous models correspond to the scenario in which buyers fully internalize their marginal energy savings, while categorical models describe situations where labels serve as salient cues for the valuation process. Despite their theoretical importance, relatively few papers examine whether different approaches yield different results and how consistent the price schedules implied by categorical specifications are with the underlying energy performance gradient. This paper addresses this gap by adopting both strategies in a multi-city setting and comparing the distribution of class-based premiums with the linear benchmark implied by energy consumption.

3 Methodological Framework

The empirical strategy involves three stages designed to estimate and compare the price premiums associated with EE through two different representations of energy performance: categorical, based on EPC classes, and continuous, based on energy consumption. Each city is analyzed independently to account for different capitalization processes in distinct local housing markets. To maintain consistency across all estimations, both approaches use the same dataset, control variables, and spatial structure. Any discrepancy in the price schedule between the two models can therefore be attributed to the way energy performance is defined.

3.1 Phase 1: Baseline Hedonic Models

Phase 1 adopts a standard hedonic pricing approach, under which housing prices reflect the implicit valuation of a bundle of dwelling attributes [21,22]. For each city, the following semi-log specification is estimated:

$$\ln(p_i) = \mathbf{X}_i'\boldsymbol{\beta} + \alpha_{\mathrm{OMI}(i)} + f(E_i) + \varepsilon_i, \tag{1}$$

where $\ln(p_i)$ denotes the logarithm of the listing price per square meter of dwelling i; $\mathbf{X}_i$ includes structural characteristics, building attributes, and amenities; $\alpha_{\mathrm{OMI}(i)}$ denotes a fixed effect associated with the Osservatorio del Mercato

Immobiliare (OMI) microzone of dwelling i; and $f(E_i)$ represents the component of the hedonic price function associated with energy performance. Estimated coefficients are interpreted as semi-elasticities, with percentage effects computed as $(e^{\beta} - 1) \times 100$.

In the first specification (A), energy performance is represented by six EPC class dummies, with class G used as the reference category and classes A1 to A4 aggregated into a single group:

$$f_A(E_i) = \sum_{k \in \mathcal{K}} \theta_k^A EPC_{i,k}, \qquad \mathcal{K} = \{A, B, C, D, E, F\}. \tag{2}$$

In the second specification (B), energy performance is modeled as a continuous variable through the non-renewable primary energy performance index ($\text{EP}_{gl,nren}$):

$$f_B(E_i) = \theta^B \, EP_{gl,nren,i}. \tag{3}$$

Under standard capitalization theory, the coefficient is expected to be negative, reflecting the inverse relationship between energy consumption and property values. Since individual-level values of $\text{EP}_{gl,nren}$ are not directly available for listings, EPC classes are mapped into a continuous proxy by assigning each class the midpoint of its relative $\text{EP}_{gl,nren}$ interval. These values should not be interpreted as absolute energy performance levels, but as normalized class-specific indicators, expressed relative to the reference building used in the certification system. For class G, which is open-ended, a representative value is obtained by extending the consumption gradient across adjacent classes, using a linear approximation based on the variation between contiguous classes. This approximation is necessary given the data availability constraints and is consistent with the structure of the certification system. However, it can introduce measurement error in the continuous specification, as within-class heterogeneity in energy performance is ignored, thereby reducing the effective variation in the explanatory variable. Table 1 reports the representative values used in the analysis.

Table 1. Relative representative values of $\text{EP}_{gl,nren}$ by EPC class.

EPC class	$\text{EP}_{gl,nren}$
A	0.50
B	1.10
C	1.35
D	1.75
E	2.30
F	3.05
G	3.97

3.2 Phase 2: Spatial Diagnostics and Spatial Model Specification

Housing prices are typically characterized by spatial dependence, as nearby dwellings share locational amenities, neighborhood characteristics, and local market dynamics. Ignoring this dependence may lead to biased or inefficient parameter estimates [23]. For this reason, the baseline OLS models are complemented by spatial diagnostics.

Residual spatial autocorrelation is first assessed using Moran's I statistic:

$$I = \frac{n}{S_0} \frac{\mathbf{e}'\mathbf{W}\mathbf{e}}{\mathbf{e}'\mathbf{e}}, \tag{4}$$

where $\mathbf{e}$ is the vector of residuals, $\mathbf{W}$ is a city-specific spatial weight matrix based on a k-nearest-neighbors structure, and S_0 is the sum of spatial weights. For each city, the minimum number of neighbors required to ensure a fully connected spatial graph is selected. When significant spatial dependence is detected, Lagrange Multiplier diagnostics are used to guide model selection. If dependence is consistent with a spatial lag process, a Spatial Autoregressive (SAR) model is estimated:

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}, \tag{5}$$

where ρ captures endogenous spatial spillover effects in price. If dependence instead reflects omitted spatially correlated factors, a Spatial Error Model (SEM) is adopted:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{u}, \quad \mathbf{u} = \lambda\mathbf{W}\mathbf{u} + \boldsymbol{\varepsilon}, \tag{6}$$

where λ measures the strength of spatial correlation in the error term. Since the two model specifications differ only in the coding of energy performance and are otherwise estimated on the same data with the same controls, the selected spatial structure is expected to remain stable within each city. This is important because it allows the comparison between categorical and continuous representations to be interpreted as substantive rather than as an artifact of different spatial specifications.

3.3 Phase 3: Comparison of Pricing Structures

The final stage involves the comparison of the price schedules generated by the two representations of energy performance. While the categorical approach generates class premiums relative to class G, the continuous approach provides a linear price-consumption schedule. To obtain comparable class premiums under the continuous approach, the estimated slope coefficient is evaluated at the representative $\mathrm{EP}_{gl,nren}$ levels for each EPC class. This comparison is particularly informative because both specifications are estimated using the same empirical setup—the same city, the same sample, the same controls, and the same spatial structure. Any difference between the price schedules is therefore not driven by technical aspects of estimation, but rather by whether market prices follow energy consumption on a proportional basis or respond to the labeling process inherent in EPC classes.

The analysis is conducted graphically and quantitatively. Graphically, class premiums are plotted against the representative consumption levels and compared with the corresponding linear benchmark implied by the continuous specification. This allows for direct detection of threshold effects, non-monotonicity, compression of premiums in intermediate classes, or disproportionate premiums at the highest efficiency levels. Numerically, the gap between the two price schedules is measured, for each city, as the sum of absolute differences between the observed class-based premiums θ_k^A and their continuous benchmark counterparts θ_k^B:

$$D_{A,B} = \sum_{k=1}^{6} \left| \theta_k^A - \theta_k^B \right|. \tag{7}$$

In this comparison, θ_k^B denotes the class-specific premium implied by the continuous model, obtained by evaluating the estimated consumption coefficient at the representative $\mathrm{EP}_{gl,nren}$ value of class k relative to class G. Higher values of $D_{A,B}$ indicate a greater divergence between the observed class-based pricing structure and the smooth proportional benchmark. Taken together, these steps provide a detailed characterization of how EE is priced in each city, making it possible to assess whether the market signal associated with EPCs is consistent with the continuous gradient of energy performance or whether it exhibits systematic distortions.

4 Case Study and Data

The empirical analysis focuses on six provincial capitals of the Veneto region: Padova, Rovigo, Treviso, Venezia, Verona, and Vicenza. The choice of these municipalities reflects the design of a comparative study aimed at assessing how energy performance is reflected in prices in different urban environments operating under the same institutional setup. There are considerable differences across these markets regarding price levels, building stock composition, urban density, and socio-economic conditions. This heterogeneity matters because it affects both the distribution of EPC classes and the economic environment in which those certificates are evaluated. At the same time, any meaningful comparison between cities requires a consistent measure of EE. This requirement is satisfied by the Italian Energy Performance Certificate (Attestato di Prestazione Energetica—APE), which classifies buildings on the basis of their $\mathrm{EP}_{gl,nren}$. This common certification framework ensures that cross-city differences in estimated price schedules can be interpreted as market-specific rather than measurement artifacts.

The dataset encompasses 5,910 residential listings collected from online RE platforms in January 2026. In the absence of publicly accessible transaction-level microdata for Italy, listing prices are widely used in empirical housing market research [15,24,25]. Although asking prices typically differ from transaction prices due to negotiation dynamics, available evidence indicates that average negotiation margins in the north-eastern Italian residential market are limited

to around 5% [26]. The discount is assumed to be relatively stable across dwelling types and market segments, and in a large and heterogeneous sample such as the one considered here, extreme negotiation outcomes are likely to average out. Moreover, the adoption of a log-linear specification implies that the analysis focuses on proportional price differentials rather than absolute price levels: since a stable negotiation margin acts as a near-constant scaling factor, its effect on estimated percentage premiums is neutralized. This makes listing prices a suitable basis for estimating and comparing energy price premiums, while acknowledging that potential systematic variation in negotiation discounts across different property types cannot be directly tested and represents a residual source of uncertainty in the estimates.

To improve the quality and comparability of the data, the sample is limited to listings published no more than six months before data retrieval. Observations lacking geographic coordinates are omitted, since geographic location plays a crucial role in the analysis. Listings with missing price information, unusual transaction types (such as auctions, bare ownership transactions, and transactions involving several properties) are filtered out, along with extreme outliers with prices below €50,000 or above €3,000,000. Duplicates are removed as well. Additional processing involves combining the structured listing information with text-extracted variables to fill gaps in the data on various property attributes, such as energy class, building condition, and building age. The final sample consists of 2,242 observations, distributed across cities as follows: Padova (693), Rovigo (159), Treviso (328), Venezia (392), Verona (326), and Vicenza (308). Average price per square meter varies from approximately €1,250 in Rovigo to more than €3,800 in Venezia, reflecting differences in market positioning and local demand conditions. For each property, the dataset includes information about property size, number of rooms and bathrooms, building age, building condition, and a large set of amenities. Each observation is matched to its OMI microzone, whose fixed effect accounts for within-city locational differences in the models. Energy performance is recoded according to the Italian EPC scale, ranging from A4 (best class) to G (worst class). In order to keep the results interpretable and to preserve sufficient numbers of observations in each class, all subclasses of class A (A4–A1) are aggregated into a single A category. Finally, in line with the methodology described in Sect. 3, each class is matched to the corresponding relative value of $EP_{gl,nren}$.

Figure 1 shows the distribution of EPC classes in each city and highlights considerable variations in the housing stock composition. Treviso, Vicenza, and Padova display relatively large shares of properties in the highest-rated classes, whereas Rovigo and Venezia show relatively larger shares of low-rated properties. These distributional differences partly reflect the quality composition of local housing supply. Treviso and Padova, for instance, have seen substantial recent construction activity, which tends to concentrate in the higher EPC classes. By contrast, Rovigo and Venezia display an older and less recently renovated building stock, which translates into lower average energy performance. This context is relevant for interpreting the econometric results, since the capitalization of

EE is likely to interact with both the informational environment and the supply composition of each local market.

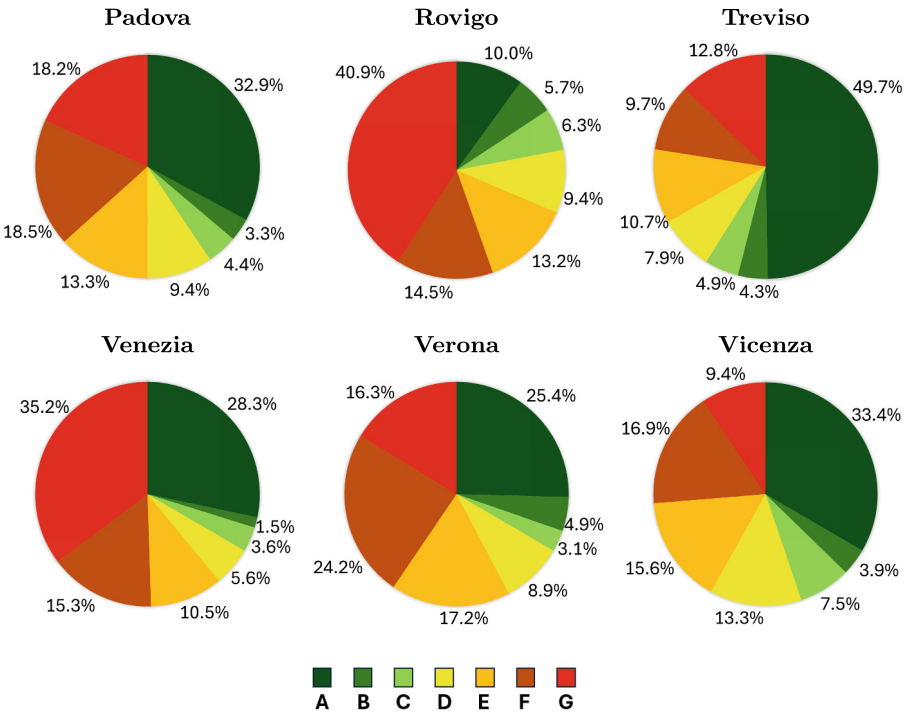

Fig. 1. Distribution of EPC classes across cities.

Table 2 summarizes the distribution of the main categorical housing characteristics by city. The descriptive evidence confirms strong cross-city heterogeneity in dwelling types, construction periods, and building conditions. This broader variation provides essential context for the econometric analysis, since the capitalization of energy performance is likely to interact with the composition and quality of the local housing stock.

5 Results and Discussion

EE is positively valued in all six housing markets, although the nature of this valuation strongly depends on how energy performance is represented. First, the econometric model specifications prove stable under both representations of energy performance. Based on residual spatial autocorrelation and Lagrange Multiplier diagnostics, OLS models are retained for Rovigo and Verona, while SEMs are selected for Padova, Treviso, Venezia, and Vicenza. This stability is

Table 2. Distribution of housing characteristics by city (%).

Variable	Level	Padova	Rovigo	Treviso	Venezia	Verona	Vicenza
Energy class							
	A	32.9	10.0	49.7	28.3	25.4	33.4
	B	3.3	5.7	4.3	1.5	4.9	3.9
	C	4.4	6.3	4.9	3.6	3.1	7.5
	D	9.4	9.4	7.9	5.6	8.9	13.3
	E	13.3	13.2	10.7	10.5	17.2	15.6
	F	18.5	14.5	9.7	15.3	24.2	16.9
	G	18.2	40.9	12.8	35.2	16.3	9.4
Property type							
	Apartment	53.8	42.1	59.2	65.5	62.6	59.7
	Penthouse	15.9	8.2	23.8	15.6	17.2	20.1
	Detached house	24.0	36.5	14.9	13.8	16.2	15.6
	Multifamily	6.3	13.2	2.1	5.1	4.0	4.6
Construction period							
	Pre-1945	8.8	1.9	5.8	37.8	18.7	7.8
	1946–1970	32.9	45.3	28.1	24.5	37.7	22.1
	1971–1990	15.4	21.4	8.5	6.6	12.9	18.2
	1991–2020	15.0	22.0	12.2	7.9	12.0	21.4
	2021–2026	27.9	9.4	45.4	23.2	18.7	30.5
Building condition							
	Good	46.3	63.5	31.7	37.0	44.2	43.2
	To renovate	8.8	15.7	9.1	8.4	8.3	7.5
	Renovated	21.1	12.6	16.5	30.9	27.6	23.7
	New	23.8	8.2	42.7	23.7	19.9	25.6
Amenities							
	Elevator	41.0	18.2	49.4	29.6	49.1	48.1
	Balcony	55.4	62.3	38.1	36.0	60.1	41.2
	Terrace	56.6	49.1	67.4	55.9	32.5	61.7
	Prestigious building	9.7	2.5	13.7	70.9	17.2	8.8
	Garage	61.8	39.6	38.4	39.0	36.5	43.8
	Parking	41.0	37.1	34.8	18.9	22.7	40.3
	Private garden	31.2	53.5	22.9	22.4	27.0	22.7
	Shared garden	25.7	15.7	17.1	26.5	18.7	28.6
	Furnished	20.2	33.3	20.1	37.8	35.0	21.4
	Air conditioning	64.1	57.2	53.4	65.1	60.4	58.1
	Optical fiber	75.0	20.1	18.0	28.1	17.5	52.9
	Panoramic view	74.2	20.1	18.0	20.9	10.1	50.0
	Alarm system	12.4	9.4	19.8	6.9	11.0	11.7
	Security door	45.0	8.8	1.0	16.8	18.4	45.5
	Laundry room	17.0	5.0	5.5	6.4	6.1	21.4
	Cellar	61.1	16.5	23.9	15.5	7.9	40.2

particularly important because it indicates that differences in estimated price schedules are driven solely by the codification of energy performance, not by changes in the underlying spatial structure.

Across both specifications, covariates show highly consistent signs, magnitudes, and levels of statistical significance. Structural features, dwelling type, building condition, construction period, and OMI fixed effects remain stable, showing that the two models describe the same price formation process in the housing market. Poor building conditions are consistently associated with lower prices, with estimated reductions ranging from −12% in Verona up to −21% in Padova and Treviso. Renovated and new houses command positive premiums, reaching up to 29% in some cases. More recent construction periods are also associated with positive premiums, although very old buildings (pre-1945) often carry positive values as well, possibly reflecting location in historic centres or the presence of architectural features valued by the market. More prestigious dwelling types, such as penthouses and detached houses, consistently attract higher prices than standard apartments. These patterns are rather stable across different cities, although the magnitude of individual effects differs considerably.

Turning to energy performance, the continuous specification yields a negative and statistically significant coefficient on energy consumption in all cities, consistent with theoretical expectations. Semi-elasticities vary from −5.31% in Venezia to approximately −9.23% in Rovigo (Table 3), indicating that higher energy consumption is associated with lower prices. The categorical specification reveals positive premiums for energy-efficient dwellings, although their distribution is irregular and appears much more flexible than under the continuous codification. In some cities, premiums change quite steadily across energy classes, while in others they show abrupt jumps, peaks at intermediate classes, and even reversals within the energy-class ranking.

Table 3. Selected model and estimated energy price premiums by city (%).

	Padova	Rovigo	Treviso	Venezia	Verona	Vicenza
Model	SEM	OLS	SEM	SEM	OLS	SEM
A	32.42	58.01	27.62	34.13	18.63	31.11
B	27.98	44.93	21.28	–1.18	21.82	26.25
C	20.54	29.53	14.83	26.68	32.01	22.75
D	18.01	35.56	15.71	8.66	21.19	29.67
E	16.81	4.08	10.87	0.82	6.20	20.45
F	16.06	22.89	2.50	8.42	6.15	14.09
$EP_{gl,nren}$	–7.06	–9.23	–6.89	–5.31	–6.22	–7.25

The two price schedules are compared graphically in Fig. 2. Treviso shows the best consistency between the two representations: the premium pattern in the EPC-based specification follows a nearly monotone progression that aligns

well with the linear benchmark. A similar pattern emerges in Padova, although with larger premiums at higher efficiency levels, suggesting that dwellings in the top energy classes attract additional value beyond what the consumption-based benchmark would imply. In both cities, the greater dynamism and activity of the local housing market appear to support a more accurate and structured capitalization of energy performance, in which price premiums align more closely with the underlying consumption gradient. At the other end of the spectrum, the largest discrepancies appear in Rovigo and Venezia, for distinct reasons. In Rovigo, the categorical premiums are markedly irregular, with large fluctuations between adjacent classes and only limited correspondence with the continuous gradient. This pattern is consistent with the characteristics of a less dynamic and less developed market, where an older building stock and a limited share of energy-efficient properties combine to amplify the perceived value of higher-rated dwellings, which may be rewarded with premiums that exceed what the consumption-based benchmark would justify. In Venezia, the pattern is characterized by discontinuities and threshold effects, including a slightly negative premium for class B and a sharp jump at the highest class. This is plausibly related to its distinctive demand profile, dominated by tourism-related and luxury demand, under which location, prestige, and architectural features drive price formation and the EE dimension carries comparatively less weight, which also explains the lowest semi-elasticity in the continuous specification. Verona and Vicenza occupy an intermediate position: in Verona, the maximum premium is observed for class C rather than class A, indicating the absence of a monotone progression; in Vicenza, there is a positive overall relationship, but classes C and B exhibit smaller premiums than D. These conclusions are consistent with the quantitative divergence measure: the sum of absolute deviations is lowest in Treviso (2.22) and moderate in Padova (5.77), compared with the higher values observed for Venezia (9.93) and Rovigo (15.1).

A relevant question concerns the extent to which these findings can be considered representative beyond the specific context of the Veneto region. The six cities analyzed fall predominantly within Italian climatic zone E, the most widespread zone in Italy. In this sense, the results regarding the relationship between energy consumption and housing prices can be considered broadly representative of this climatic context, where heating and cooling demand profiles are similar across cities. At the same time, the considerable heterogeneity documented across cities within the same region suggests that how EPC labels are perceived and processed by market participants differs substantially depending on local market dynamics, so that even within a shared climatic context the capitalization pattern cannot be assumed uniform. Generalizability to other climatic zones warrants further caution: where heating demand is lower or cooling costs are dominant, the energy demand profile changes considerably, and the economic benefit associated with a given EPC class may be perceived differently by market participants, potentially altering both the magnitude of estimated premiums and the degree to which categorical labels diverge from the continuous consumption gradient.

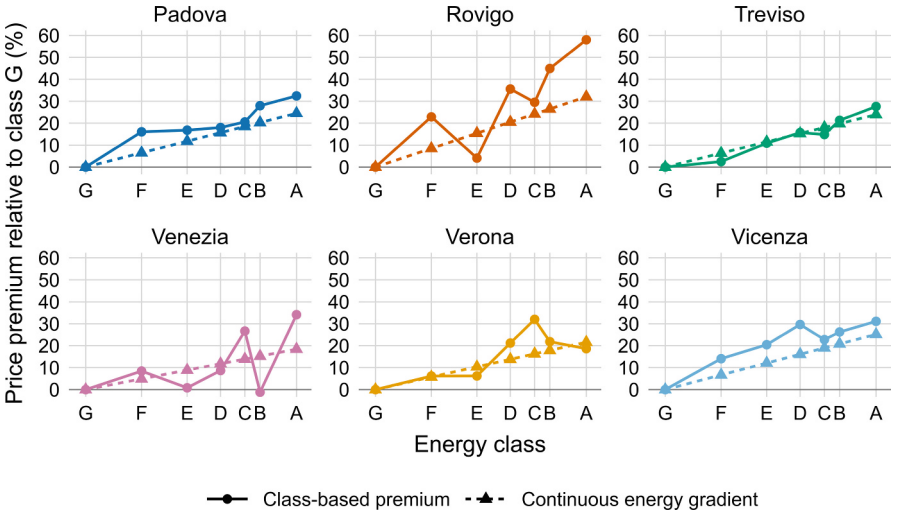

Fig. 2. Comparison between class-based and continuous consumption-based price premiums across cities.

Before turning to the broader implications, it is necessary to discuss the main limitations of the study. A first concern relates to sample size: in some cities, the number of observations in certain energy classes may be insufficient, leading to greater variability in the estimates and possibly to apparent irregularities in the premium schedule driven by sampling error rather than by genuine market behavior. This problem is most acute in thin markets such as Rovigo, where few transactions can amplify the apparent magnitude of discontinuities. A second limitation concerns the continuous specification of EE: as discussed in Sect. 3, the use of class-level representative values of $EP_{gl,nren}$ neglects within-class heterogeneity in energy performance and likely generates attenuation bias, so that the estimated consumption-price gradient should be treated as a stylized benchmark rather than a precise estimate. A third limitation concerns the use of listing prices rather than transaction prices. While the log-linear specification attenuates the impact of stable negotiation margins on estimated differentials, the assumption that negotiation discounts do not systematically vary with energy performance cannot be directly tested. If energy-efficient properties tend to attract more competitive offers, the estimated premiums may overstate the true transaction-price differentials. Overall, these limitations do not undermine the main comparative insights of the analysis, but access to transaction-level microdata including property-specific energy consumption would allow for more precise estimation and represents an important avenue for future research.

Despite these limitations, the implications for the understanding of how housing markets value EE are highly relevant. From a market perspective, the results highlight that the capitalization process is driven by the way information is perceived and interpreted. While the consumption specification identifies the

underlying physical dimension of performance, the categorical estimates show that buyers and sellers tend to react to EPC labels as simplified signals. EPCs seem to operate as heuristics—salient and easily understandable categories that shape quality expectations and operating cost perceptions—but they do not necessarily replicate the underlying consumption gradient in a proportional manner. This explains the occurrence of threshold effects, local amplifications, and non-monotonicities, which appear to be more frequent in markets characterized by higher information frictions and less structured demand.

From a policy perspective, the implications are equally relevant. The primary purpose of EPCs is to overcome information asymmetries and foster efficient housing choice and renovation by making energy performance transparent. However, the evidence presented here suggests that market signals may fail to properly reflect the economic value of energy savings. When prices respond discontinuously to categorical labels rather than continuously to the underlying performance gradient, investment incentives become distorted: threshold effects generate excessive premiums for properties that just cross a class boundary, while improvements that remain within a class may go unrewarded. The non-equidistance of EPC class intervals compounds this problem, since identical improvements in EE do not translate into equal class changes and therefore do not produce equal market rewards.

Overall, this analysis suggests that EPC-based public policies could benefit from the more prominent integration of consumption indicators alongside existing class labels, making the continuous dimension of energy performance more visible and accessible to market participants. Policy interventions should also account for the role of local heterogeneity: the informational effect exerted by the same classification system appears highly variable across housing markets, and a uniform policy approach is unlikely to be equally effective in contexts as different as Treviso and Venezia. More targeted and context-sensitive interventions, designed with awareness of local market structure, demand characteristics, and housing stock composition, are likely to produce more effective outcomes.

6 Conclusion

This study investigates how residential housing markets capitalize EE by comparing two alternative representations of energy performance: a categorical one, based on the classification of properties according to EPCs, and a continuous one, based on non-renewable primary energy consumption values. Using property-level listing data collected for six provincial capitals in the Veneto region, city-specific hedonic models with spatial controls are estimated to test whether class-based energy price premiums align with the underlying energy performance gradient or are driven by the discrete nature of EPC labels.

The empirical results show that EE generates a positive price premium in each of the six investigated cities. Under the continuous specification, the association between non-renewable primary energy consumption and housing prices is negative and consistent with a proportional capitalization of energy performance

benefits. The categorical specification, by contrast, frequently deviates from this benchmark: in Treviso and Padova the premium pattern tracks the consumption gradient reasonably well, while in Rovigo and Venezia it is characterized by threshold effects, non-monotonicity, and discontinuous jumps between adjacent classes. These findings suggest that EPCs play a dual role as market signals. On the one hand, they convey information about the actual energy performance of properties and the potential savings associated with lower energy costs. On the other hand, as categorical labels, they present this information in a simplified form that is not always consistent with the underlying performance gradient. Recognizing these mechanisms is important both for the interpretation of estimated energy premiums and for the design of empirical strategies capable of accounting for the physical and informational dimensions of energy performance in housing markets.

Looking ahead, several directions for future research emerge. In particular, access to transaction-level microdata with property-specific energy consumption measures would allow for more precise estimation of capitalization effects and a direct comparison between listing and transaction prices. Moreover, further research could explore how the informational role of EPCs varies across different climatic and market contexts, where the relative importance of energy demand components and local housing dynamics may alter the way energy performance is capitalized.

Acknowledgments. The article is the result of a research activity carried out with funding from the Giorgio Levi Cases Centre for Energy Economics and Technology at the University of Padova, within the framework of the EVeREST project (Energy efficiency Value in REsidential STock).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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