

Unraveling the Role Played by Energy Rating Bands in Shaping Property Prices Using a Multi-criteria Optimization Approach: The Case Study of Padua's Housing Market

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Abstract. As the topic of energy efficiency is still in the spotlight after a few decades of studies delving into it, several dozens of recent publications deal with the potential occurrence of a price premium for green buildings, namely, those significantly outperforming the best conventional ones. Almost all of those investigations find that a price premium indeed occurs and is statistically significant - though its magnitude is still debated - using regression analysis. Especially, the traditional hedonic price model is widely used in early studies, while the spatial autoregressive and spatial error models are ever extensively employed in the newest ones. Here we suggest using a different approach by turning to multi-criteria analysis. In particular, we propose combining an application of the analytical hierarchy process and linear optimization to identify the role played by energy rating bands and the energy performance index in shaping property prices. As a result, we expect to estimate the likely magnitude of the price premium for building energy efficiency. We test the approach on the local housing market in Padua, North-eastern Italy. A strong influence is found to be exerted on property prices by the energy performance as expressed by the rating bands. After discussing the empirical findings and the limitations of the analytical procedure, we also outline further developments for our multi-criteria approach.

Keywords: Multi-criteria decision support systems · Green buildings · Building energy efficiency · Energy performance certificates · Energy rating bands · Property prices

1 Introduction and Background Literature

The topic of energy efficiency has been in the spotlight at least for four decades or so, roughly starting from the oil shocks experienced during the seventies [1, 2], and energy efficiency of buildings is one of the most important research branches [3] since they contribute to a large part of energy consumption and greenhouse gas emissions [4, 5]. Two intriguing issues about building energy efficiency are as follows [6]: whether pursuing higher energy performance implies the need to incur higher construction costs -

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hence, the occurrence of a cost premium - is the first; whether higher energy performance is rewarded by the players in the real estate market with a higher willingness to pay - hence, the occurrence of a price premium - is the second.

As far as the first issue is concerned, green buildings are often considered more expensive than traditional ones, roughly in the range between 5% and 20% [7–12], depending on the performance rating [13] or energy saving [14]. The higher upfront cost would represent a market barrier to their spread so as to slow down the desirable renovation of the building stock [15]. As a matter of fact, still recently, the renovation rate is found to remain very low across the EU Member States - about 1% on average, with an upper bound of only 1.2% and a lower bound as small as 0.4% [16] - while the optimal rate should be double, at least [17, 18]. Nevertheless, the literature has not come to compelling and conclusive evidence of a cost premium yet. Several studies point out that the additional cost, if any, could be pretty small [7, 19]. Furthermore, research on LEED and Green Star certified properties finds no difference in the construction costs or a small gap, yet not statistically significant [20, 21].

Concerning the second issue, the financial benefits related to improving building energy performance are thought to be the ground of successful regeneration projects [22, 23], and a much broader corpus of studies deal with the investigation of the occurrence of a price premium [1, 24, 25]. While early analyses date back to the late eighties [26, 27], most of the studies on the topic have been published during the last decade or so. Though a few works cast doubt on the occurrence of a price premium for high-performance properties [28–30], a higher willingness to pay for green building units has been found in dozens of studies published so far. Market players are likely to pay more both for residential [31–35] and commercial [36–41] properties. As regards dwellings, several analyses focus on the additional price related to the Green Mark (GM) certification scheme adopted in Singapore, finding premiums ranging between 1.3–9.1% for GM Certified buildings and 8.0–39.7% for GM Gold or Platinum units [42–46]. Besides, many studies take advantage of the Energy Performance Certificate (EPC) system introduced in the European Union by the Directive 2010/31/EU. The EPC rating scheme is thought to lack the ability to lessen market inefficiencies, such as information asymmetries, and push energy efficiency [47–50]; it is also found to have flaws and drawbacks [51–53], especially misjudgments and assessment distortions are mentioned as major issues [54–56]. Nevertheless, as the scheme implementation goes on, it makes it possible to investigate whether or not the energy rating bands command a price premium when building units are sold or rented. The works focusing on EPCs agree in finding that a positive price premium occurs, though its magnitude is still debated. There is broad consensus towards a premium within 10% when comparing the A and B energy rating bands to the D one [57–62], but sometimes it is also found to go up to 20% [63–65] and even higher in a few studies [24, 66, 67].

The analysis into the occurrence of a price premium for energy efficiency in buildings poses several methodological issues. One of them is as follows. Most of the literature dealing with the topic makes use of regression analysis to find out whether it occurs and whether it is statistically significant or not. Early studies employ the traditional hedonic price model [58, 68, 69], seldom adopting a double-log functional form of the model [70–73], much more often using a semi-log functional form [74–76], also controlling for

time and space fixed effects [77–82]. Recently, ever extensive use of spatial data analysis [83, 84] has been seen, especially the spatial autoregressive model [33, 85–89] and the spatial error model [46, 90]. Occasionally, different models have been tested, such as logistic regression [57], quantile regression [62], geographically weighted regression [88], and hierarchical Bayes model [43]. Though there are well-founded reasons why regression models are usually employed in this research strand, the lack of testing for different approaches is somewhat surprising.

Here we propose to turn to multi-criteria analysis to start filling this gap. Multi-criteria methodologies have been adopted in other studies involving the energy efficiency of the real estate market, especially for selection and ranking purposes as far as efficiency measures and policies are concerned [91, 92]. However, to the best of the authors' knowledge, it has still to be fitted into a research issue such as the measurement of the magnitude of the price premium for building energy efficiency, which is generally addressed using different approaches, and this is precisely the original contribution this paper is meant to provide.

The remainder of this paper is organized as follows. Section 2 provides an overview of the multi-criteria optimization approach we propose here. Section 3 introduces the case study focused on Padua's housing market and the data we gathered and processed to test the method. Section 4 presents and discusses the results of the analysis. Section 5 discusses the limitations of the approach we use here and outlines further developments. Section 6 draws the conclusions.

2 Method and Models

2.1 Multivariate Regression Model

Essentially, the studies analyzing the occurrence of a price premium in green buildings using multiple regression models come on the heels of the seminal work authored by Rosen in 1974 [93], where the price P of a property is modeled as a function of k so-called "utility bearing attributes" (p. 34) x:

$$P = f(x_k) \tag{1}$$

The model derived from Rosen's insight into how differentiation of products - according to a set of significant characteristics - affects their value can be written in full as follows:

$$P = \alpha + \beta_k x_k + \varepsilon \tag{2}$$

where α is the constant, β are the coefficients associated with each of the k significant attributes or characteristics x, and ε is the error term. The focus is on energy efficiency as one of the significant attributes; it can be included in the model of Eq. (2) using the energy performance index as an independent variable or instead several dichotomous variables, each of them representing an energy rating band.

Most of the literature cited earlier transforms Eq. (2) into the semi-logarithmic (semi-log or log-linear) functional form by taking the logarithm of the dependent variable,

which is common in econometric analysis because one can then easily interpret the β coefficients:

$$\ln P = \alpha + \beta_k x_k + \varepsilon \tag{3}$$

Thanks to Eq. (3), the β_k coefficients can be used to identify the percentage changes in the dependent variable commanded by a unit variation in attributes or characteristics x, according to the following calculation as suggested in the literature [94]:

$$\Delta P = e^{\beta_k} - 1 \tag{4}$$

2.2 Multi-criteria Optimization Model

Here we aim to match the multivariate regression model introduced in the previous subsection, especially the log-linear model of Eq. (3), with the multi-criteria model of the analytic hierarchy process (AHP) outlined by Saaty between the late seventies and the early eighties [95–97]. Let us define the hierarchical value tree as follows:

- the goal is to rank a set of real estate assets according to their market value, with the most valuable properties at the top of the ranking and the less valuable ones at the bottom;
- each criterion corresponds to the kth attribute x_k (with $k = 1, \ldots, l$), which is thought to play a role in shaping the market value of the analyzed real estate assets;
- the alternatives are i properties; we primarily focus on housing and take into consideration dwellings characterized by different structural, locational, and other attributes [98].

Let us suppose we build a pair-wise comparison matrix of size n x n to compare the ith and jth properties (with $i, j = 1, \ldots, n$) using the ratios between their prices, so that:

$$m_{i,j} = P_i / P_j \tag{5}$$

$$m_{i,i} = P_i / P_i = 1 \tag{6}$$

$$m_{j,i} = \frac{1}{P_i / P_j} = P_j / P_i \tag{7}$$

As usual in the AHP, the entries in the main diagonal are all equal to one according to Eq. (6), while the values in the lower triangle are the reciprocal of the elements in the upper triangle according to Eq. (7).

In order to get the rating for each property, the nth root of the product of the values in each row of the pair-wise comparison matrix is calculated and then normalized:

$$w_i = \sqrt[n]{\prod_{j=1}^{n} m_{i,j}} \Big/ \sum_{i=1}^{n} \sqrt[n]{\prod_{j=1}^{n} m_{i,j}} \tag{8}$$

Separately, we also build m pair-wise comparison matrices, each of size n x n, to compare the ith and jth properties using the ratios between the values x_{ki} and x_{kj} for each kth attribute. The priority p_{ki} for each property i on each attribute k is then derived according to the calculation in Eq. (8), while the weighting $\widehat{\beta}_k$ for the attributes - that is to say, the criteria - is derived again according to the calculation in Eq. (8) from the specific pair-wise comparison matrix where they are compared. An estimate of the rating for each property is finally calculated as follows:

$$\widehat{w}_i = \sum\nolimits_{i=1}^{n} p_{ki}\widehat{\beta}_k \tag{9}$$

What is left is to vary and adjust $\widehat{\beta}_k$ so that $\widehat{w}_i$ is overall as close as possible to w_i. We pursue this goal by minimizing a loss function based on the notion of squared distance that resembles the least square method as in regression analysis:

$$\min_{\widehat{\beta}_k} \sum\nolimits_{i=1}^{n} \left(w_i - \widehat{w}_i\right)^2 \tag{10}$$

The weights $\widehat{\beta}_k$ for the attributes - or criteria, if you will - resulting from the optimization in Eq. (10) can be interpreted as a sort of proxy of the β_k coefficients in Eqs. (2)–(3); thus, an estimate - expressed in percentage - of the contribution of each attribute in shaping the property price.

3 Case Study: Padua's Housing Market

We focus on Padua's housing market - previously analyzed in terms of building energy efficiency [24, 60, 99] - to test the multi-criteria optimization approach outlined in the previous section. Below are further details about the data gathering process and sources.

As far as the data gathering process is concerned, we follow the approach adopted in a previous publication [24] and pay exclusive attention to a housing submarket primarily defined by typology, size, and location. We checked several dozens of real estate advertisements to identify a set of properties for sale meeting the following criteria: flats, terraced houses, and two-family houses as far as the typology is concerned; small to average size of the dwelling, namely, up to 130 square meters; location outside the old town, in inner-ring neighborhoods, thus at a distance greater than or equal to 3.4 km from the center. Fifteen properties were selected to be further processed.

Based on the information included in real estate advertisements, we collected the following data for each property (Table 1): listing price (LP); saleable area (SA); unit price (UP), that to say, the ratio between the listing price and saleable area; building typology; number of bedrooms (RM) and bathrooms (BR); presence of a garage or privately-owned parking lots; presence of "out of the ordinary" equipment. Also, in compliance with the national rules adopted following the European Directive on the energy performance of buildings (2010/31/UE), real estate advertisements are supposed to include both the energy rating band of the building unit and its energy performance index (EPI), which are crucial for the analysis we propose. Finally, we kept track of the geolocation of each property, so that to be able to calculate additional variables based on distances: to the city center, the nearest shopping center, and the nearest ramp of the beltway.

Table 1. Descriptive statistics for quantitative variables.

	Unit of measure	Mean	St. dev.	Min.	Max.
LP	Euros	167,667	54,964	98,000	300,000
SA	m^2	98	25	25	129
UP	Euros/m^2	1,822	706	940	3,920
RM	n	3.0	1.1	1.0	5.0
BR	n	1.8	0.4	1.0	2.0
EPI	kWh/m^2 y	147.70	97.56	3.51	292.00

4 Results and Discussion

4.1 Weights of the Attributes with Regard to the Listing Price of the Properties

As far as the listing price is concerned, we get comforting results, in line with expectations (Fig. 1). In particular, on the whole, the location attributes contribute to about one-third (34%) of the listing price, most of all because of the proximity to the city center (15%) and the nearest shopping center (19%). This outcome is in line with the parameter of land leverage [100, 101] - that is to say, the ratio between the land value and the overall market value of a property - which is known to range in the city of Padua from 23% for suburban neighborhoods, to 27% for inner-ring districts, to 41% for downtown areas [102, 103]. Building attributes cover the remaining share of the listing price (nearly 66%), about half of which is related to the energy rating band (36%). As pointed out in a previous study [24], the significant role played by energy efficiency in shaping property prices may be symptomatic of the fact that the energy rating bands themselves absorb other meaningful features, such as the use of state-of-the-art building materials, cladding, insulation, finishes, and systems.

Another interesting result, which is worth mentioning, occurs when replacing the energy rating band with the energy performance index. While the former weighs more than a third (36.0%), the latter is found to represent just a tenth (10.1%) of the listing price. The discrepancy is hardly explainable since there is almost an inverse relationship between the two variables at hand (Fig. 2), unless assuming that market players have a deeper understanding of the energy rating bands than they have of the energy performance index. In other words, aside from the fact that a nonlinear function may best fit the relationship between rating bands and index, the meaning conveyed by the energy rating bands - as well as by all the building features behind them - may be easier to grasp than the information brought by the energy performance index, so that they may be more suitable to represent the willingness to pay for dwellings characterized by high performance.

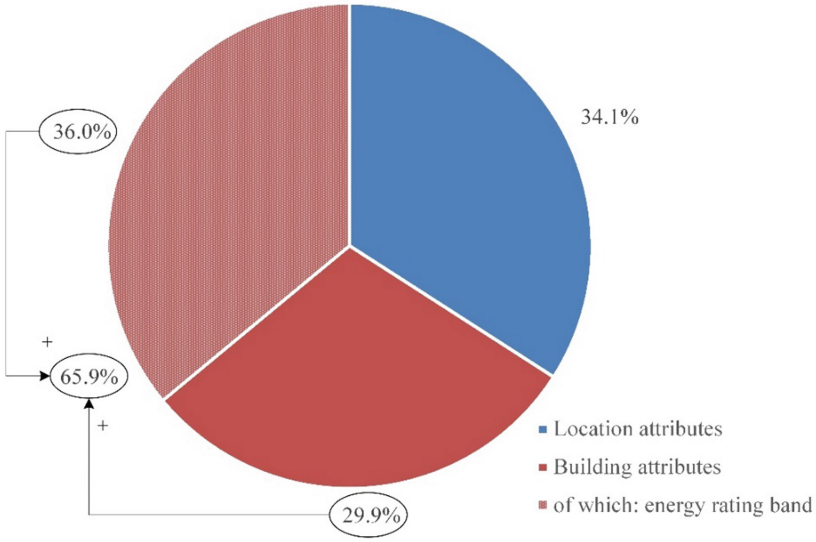

Fig. 1. Contribution of the attributes to the listing price, with a focus on the energy rating band.

4.2 Weights of the Attributes with Regard to the Unit Price of the Properties

Turning to the study of the unit price of the properties (Fig. 3), the most remarkable novelty lies in the fact that - as expected - the saleable area plays a major role. The weight this attribute takes on as a criterion means that it contributes to shaping up to nearly half the price (46.5%).

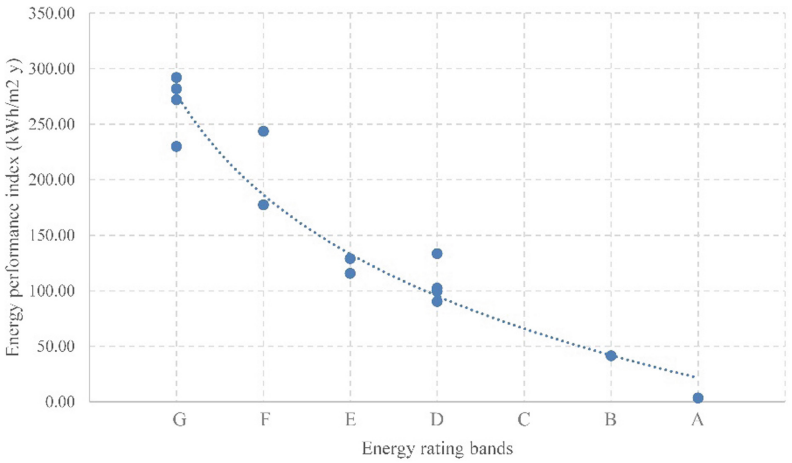

Fig. 2. Inverse relationship between energy rating bands and energy performance index.

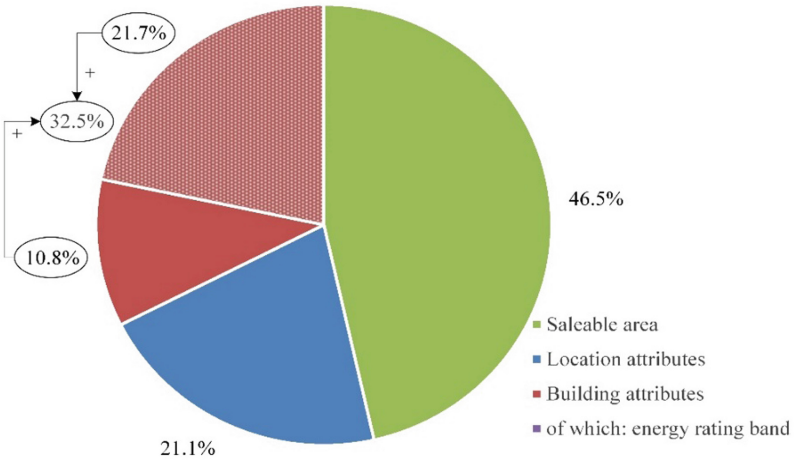

Fig. 3. Contribution of the attributes to the unit price, with a focus on the energy rating band.

Aside from that, location attributes shape about a fifth of the unit price (21.1%), again primarily because of the proximity to the city center (12.9%) or the nearest mall (7.7%), while the building characteristics explain the remaining third of the unit price (32.5%). We get additional evidence that energy rating bands are among the most prominent building features since they shape alone more than twenty percent (21.7%) of the market value. Also, in keeping with the discussion in the previous subsection, we find that the unit price is much less sensitive to the energy performance index (8.2%).

5 Limitations and Further Developments

This study suffers from a few limitations, which we mean to address in further developments of the research strand.

In the first place, we choose to limit the sample size to fifteen residential properties mostly because the case study is used here as a testbed. A brief digression is in order here. It would be helpful to apply traditional regression methods to the same case study to verify the effectiveness of the model we propose. That would enable us to compare the results and judge the computational performance of the different approaches. Unfortunately, the small sample size prevents this test from being performed. However, the small sample size enables us to take under control the issues related to the consistency of pair-wise comparison matrices. In fact, the bigger the size of such matrices, the more likely are violations of transitivity of preferences, which is a fundamental property of the approach we adopt. Nevertheless, since we use ratios as pair-wise comparison judgments, those matrices are perfectly consistent; namely, transitivity of preferences is always met. The latter observation paves the way to the use of far bigger samples, as the size of the matrices is no more an issue. Perhaps, larger sample sizes could help address the gap in weights between the energy rating bands and the energy performance index, which is a crucial issue. For that matter, the use of additional building attributes - hence, criteria - in the model sinks its roots in the same reason.

Secondly, once settled that energy rating bands do matter in shaping property prices and identified their overall weight, it seems essential to dig deeper in order to determine the marginal price associated with each change in rating. In fact, the fundamental issues to address are, for instance, whether A-rated properties are sold at a premium compared to the B-rated ones, whether there is a price premium distinguishing B-rated and C-rated properties, and so forth. The magnitude of the price premium, if any, can be unraveled by the method and model we propose here, performing the analysis on subsamples, which include buildings belonging to just two energy rating bands at a time.

Thirdly and lastly, it is worth mentioning another issue, which is distinguishing and isolating the contribution to property price brought by the energy rating band on its own from that conveyed by related building attributes such as the presence of state-of-the-art materials, finishes, and systems. Though there is no guarantee that the model we use here can provide significant outcomes, it seems worth trying to include those attributes in the model and perform the analysis posing constraints on their weights to check how this affects the role played by the energy rating bands.

6 Conclusions

This study aims to verify the role that energy efficiency - as expressed by the rating bands and the energy performance index - plays in shaping the price of real estate assets. Instead of using traditional multivariate regression models, here we propose a multi-criteria optimization approach, building on the method of analytic hierarchy process. In essence, each statistically significant building characteristic in the regression model is translated into an assessment criterion in the multi-criteria approach. Then, the weights of the criteria - namely, the building characteristics - that match the ranking of the properties according to their prices are found.

Using Padua's housing market as a testbed, we process the data concerning fifteen properties and their main location attributes (e.g., distance to the city center and the nearest shopping center) and building features (e.g., typology, number of rooms and bathrooms). As far as the results are concerned, we find that the overall weights of location and building factors align with the expectations. Furthermore, as expressed by the energy rating bands, energy efficiency is significant among the building attributes, which means it plays a significant role in shaping property prices. Notably, despite the strong relationship that ties them together, the energy performance index is not as important as the energy rating bands are.

We see further developments for the approach we propose here. In particular, the model lends itself to being used on much larger samples, as in our case, the sample size is not an issue for constructing consistent pair-wise comparison matrices. It is also suitable to be used in order to identify the marginal price related to changes in the energy rating band.

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