Impact of the 2022 Energy Crisis on the Importance of Energy Performance Certificates for the Real Estate Market*

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This study relies on a unique database covering different segments of the residential real estate market to investigate whether the value of energy performance certificates was affected by the energy crisis in 2022. Based on the relevant literature, the study uses the linear regression estimation method, in which the effect of interaction is examined using the difference-in-difference method. The study shows that energy performance certificates have a significant impact on the estimated market value of properties, both by individual category and in groups. While in 2022 Q2, before the residential energy price increase, an energy-inefficient property cost 12 per cent less on average compared to a property with an average energy rating, controlling for other factors, that difference increased to 20 per cent after the outbreak of the energy crisis. It may therefore be worthwhile for Hungary to consider taking measures to improve the energy efficiency of buildings as soon as possible.

Journal of Economic Literature (JEL) codes: O13, Q40, R30, R31

Keywords: housing market, energy crisis, sustainability, energy performance certificate

1. Introduction

'The world is on the brink of the worst energy crisis since the 1970s'
(*Jason Bordoff, 2022*)

The quote above comes from energy policy expert Jason Bordoff, a professor at Columbia University. The ominous phrase was uttered in the context of the Russian-Ukrainian war that broke out in February 2022, when restrictions on energy in the context of the war led to a surge in energy prices and insecurity of energy supplies.

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Europe has been particularly strongly affected by the energy crisis due to its heavy dependence on Russian energy imports. The energy crisis has brought the issues of sustainability and energy efficiency even more to the fore, which is also true for the real estate markets. Improving the energy efficiency of building stocks may make a significant contribution to the fight against global warming (*Baji et al. 2023*).

According to the business press, interest in energy-efficient properties in Hungary has recently increased.[1] In addition to higher utility costs, this is probably due to the fact that the majority of Hungarian properties are significantly below the level of modern energy-efficient properties in terms of energy efficiency (*Bereczki et al. 2022*). Based on energy performance certificates, the share of properties with at least a modern energy performance classification in the housing stock was only somewhat higher in 2021 than in 2016 (*Ritter 2022*). This discrepancy might also be linked to the higher share of newly-built properties within the certificates.

As tensions in the energy market are not transitory, there is added value in focusing on the period of the energy crisis. It may be useful for several reasons to map how the pricing of energy efficiency in the real estate market has changed and to what extent this factor is currently priced in. On the one hand, at the level of individuals, it helps homeowners to price their property, develop a property investment strategy and, perhaps most importantly, assess energy modernisation options. On the other hand, at a societal level, governments can take forward-looking measures to improve energy efficiency, thereby reducing the risk of energy dependence and helping to meet climate targets to fight global warming. The extent of change (over a short period of time) may also provide valuable information for behavioural economists, as well as real estate market and macro modellers.

The research question of the study is whether the energy crisis of 2022 has had an impact on the relationship between property value and energy performance certificates. A related hypothesis is that the importance of energy performance certificates in the real estate market has increased significantly since the energy crisis. In this study, the onset of the energy crisis is defined as the change in the regulation of utility costs in Hungary. The data for the research is provided by the mortgage data of a commercial bank in Hungary, which contains property valuation data for the year 2022. The linear regression methodology was used for the research, in which the effect of the interaction of the energy crisis and energy performance certificates is examined using the difference-in-difference method.

We demonstrate that since the beginning of the energy crisis there has been a statistically significant change in the value of energy performance certificates for energy-inefficient buildings. Before the rise in household energy prices, an energy-

[1] Forbes (19 April 2023). *Housing market: that's what good insulation means in terms of price*. https://forbes.hu/penz/lakaspaic-szigeteles-ingatlan-napelem/. Downloaded: 7 February 2024.

inefficient property cost 12 per cent less on average compared to an average energy-efficiency property, controlling for other impacts, while this difference averaged 20 per cent in the third and fourth quarters of the year, after the onset of the energy crisis. As a combined effect, the value of HH–JJ category homes was nearly 1 per cent lower in the fourth quarter compared to the pre-energy crisis period (second quarter), despite the overall (nominal) house price increase observed during the period. Consistent with previous findings in the literature, for the sample as a whole,[2] we find that energy performance certificates have a significant explanatory power on property values: compared to average energy-efficiency buildings, energy-efficient homes cost 7 per cent more on average, while energy-inefficient properties cost 17 per cent less on average, other effects considered. Looking at individual energy performance certificate categories, almost all categories reflect a significant increase in the estimated market value of the property compared to the lowest-rated building; GG-certified properties are 12 per cent more expensive on average, while the highest AA–BB category properties are more than 35 per cent more expensive.

Thanks to the unique database, the study contributes to the literature in two ways: to the best of our knowledge, our work is the first scientific study in Hungary that examines changing preferences towards the energy consumption of properties, as reflected in real estate prices, in a period of energy uncertainty and energy price increases. Additionally, it enables more general conclusions concerning the residential real estate market, as the scope of our study is not limited to certain market segments.

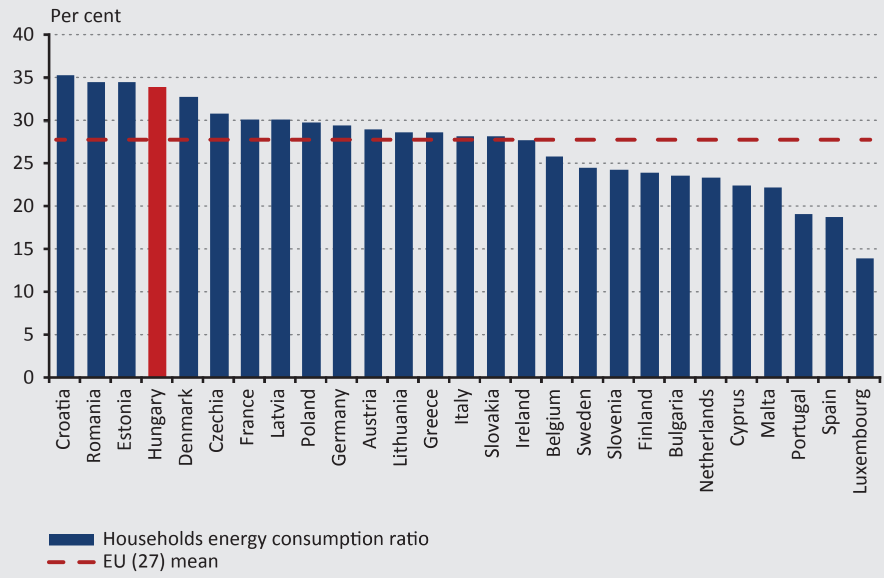
Section two of the paper puts the research question in the context of sustainability and energy efficiency, before discussing the regulation of energy performance certificates in Hungary, the current situation of the real estate market and the circumstances of the energy crisis in Hungary in 2022. *Section three* reviews the relevant literature on energy efficiency and house prices. *Section four* presents the data used in the study and their characteristics, followed by a description of the methodology. *Section six* describes the results of the research in detail, with a special focus on the interaction term of energy performance certificates and the energy crisis. This is followed by a statement of the limitations of the research. Finally, the summary outlines broader perspectives and draws conclusions.

[2] Including the months before and after the energy crisis began.

2. Sustainability and energy efficiency in the real estate market

The issue of sustainability and global warming has undoubtedly become one of the most discussed topics. As the energy consumption of buildings plays a significant role in sustainability, one important question is what can be done to reduce that need (*Da Cunha – De Aguiar 2020*). The severity of the problem is underlined by the fact that in 2021 residential energy use in Hungary accounted for 34 per cent of total energy use,[3] due to buildings that mostly rely on the use of obsolete types of energy. As *Figure 1* shows, this is the fourth highest figure in the European Union and is significantly higher than the EU average of 27 per cent.[4]

Figure 1
Use of residential energy in EU countries as a percentage of total energy consumption



Source: Eurostat

[3] Source: Hungarian Central Statistical Office (HCSO): *Final energy consumption by sector*. https://www.ksh.hu/stadat_files/ene/hu/ene0006.html. Downloaded: 20 March 2023.

[4] Source: Eurostat: *Final energy consumption by sector.* https://ec.europa.eu/eurostat/databrowser/view/ten00124__custom_7920493/bookmark/table?lang=en&bookmarkId=1a5f18a1-7dbe-4565-8602-a21cc3849f7f. Downloaded: 14 October 2023.

The energy efficiency of a building is influenced by a number of factors, which, according to *Chen et al.* (*2020*), can be divided into three broad categories: (1) the insulation and quality of windows and doors; (2) the cooling and heating systems of the building, the proportion of energy-efficient lighting and appliances and related intelligent control systems; and (3) the location of the property and local weather conditions, which have recently started to receive more attention in economics literature.[5] Use of the term 'energy-efficient building' (*Khosla – Singh 2014*) is becoming increasingly widespread, referring to buildings that help reduce the rate of global warming by using energy and water more efficiently and encourage the use of renewable energy sources. In the future, two key factors will thus dominate the real estate markets: reducing the environmental impact of buildings, and reducing the energy demand of buildings when constructing new properties or renovating existing ones (*Ionescu et al. 2015*).

2.1. The concept of energy performance certificates

In order to measure the energy efficiency of individual buildings, an increasing number of countries require an energy performance certificate. This has been a legal requirement in Hungary since 2012 for new buildings and for the sale of existing buildings.[6] This means that not all properties are certified yet, but as time goes by, more and more buildings will be subject to an energy analysis. The scale of the certificate varies from country to country. Between 2016 and 2023 a 12-step scale was applied in Hungary, with AA++ and JJ as the best and the worst rating, respectively (*Takarék Index 2022*).[7] In 2022, 20 per cent of properties were covered by certificates based on the 12-degree scale (*Bereczki et al. 2022*); however, they were unevenly distributed throughout the country. For example, in 2020, when the national coverage was 15 per cent, this share was 9 per cent in the municipalities of Southern Great Plain and 19 per cent in the towns of Pest County (*Bene et al. 2023*).

An explanation of each category is summarised in *Table 1*. The 12-grade scale can be divided into 3 major groups: the designations AA++, AA+, AA, BB and CC refer to the highest-rated energy-efficient properties, with AA–BB homes having at least 25 per cent renewable energy demand. The EU Taxonomy requires a near-zero energy demand for energy-efficient properties, and this requirement is not satisfied by CC-rated homes; however, since the CC rating has been the requirement for new-built properties for a long time and there are comparatively few AA–BB category properties in our sample, we include the CC category in the sufficiently efficient

[5] *Baranyai – Banai (2022*) is relevant for the relationship between the location of the property and weather conditions. Point 3) appears in few economics studies, and this focus is novel from an economics point of view.

[6] Government Decree No. 176/2008 (VI. 30.) on the certification of the energy performance of buildings

[7] While it was replaced by a new certification scheme in November 2023, the study uses 2022 data to examine the previous certification system.

group. Properties labelled as DD, EE, FF and GG have an energy rating around the average, while HH, II, JJ are considered energy-inefficient homes (*Horváth et al. 2013; Ramos et al. 2015*). Measurements for energy performance certificates are carried out by professional companies established for this purpose and the measurement result remains valid for 10 years from the date of issue (*Ertl et al. 2021*).

Table 1
Categories of energy performance certificates in effect since 2016 and their explanation

Energy-efficient properties	AA++	<40%	Minimum energy demand
	AA+	40–60%	Outstanding energy efficiency
	AA	61–80%	Better than near-zero energy demand
	BB	81–100%	Near-zero energy demand
	CC	101–130%	Modern
Buildings with average energy use	DD	131–160%	Close to modern
	EE	161–200%	Better than average
	FF	201–250%	Average
	GG	251–310%	Close to average
Energy-inefficient homes	HH	311–400%	Weak
	II	401–500%	Poor
	JJ	>500%	Very poor

Note: The third column shows the value of the aggregated energy performance as a percentage of the prescribed energy performance requirements in the legislation. For newly-built properties, this value can be up to 76 kWh/m², which corresponds to a near-zero energy building.

2.2. Characteristics of the property market in Hungary

Hungary has one of the highest levels of residential energy use within the EU (*Koltai et al. 2021:10*), *as* the vast majority of Hungarian buildings are outdated from an energy point of view. This means that rising energy costs are a key problem. The energy efficiency of a property is strongly influenced by the year it was built and whether it has undergone any major renovation in recent years. The latter is of particular importance as Hungary has an extremely high number of buildings built before the political transition (65 per cent of the total housing stock was built before 1981),[8] and those buildings are now considered outdated (*Takarék Index 2022*). Homes with inefficient energy use not only have a negative impact on the

[8] Source: HCSO: *Rooms in homes by country district.* https://nepszamlalas2022.ksh.hu/adatbazis/#/table/WBL006/N4IgFgpghgJiBcBtEAVAkgWQKIH0AKWASmgPIAiIAugDQgDOAljBAslgQGr4kDCAjFVp0IAYwAuDA-PYA7VjRAAzBgBsxEAE50EoANYNpceCAxQADiFoRpY9QwhaklAL5OgA=. Downloaded: 7 February 2024.

environment, they also have significantly higher utility costs. According to *Koltai et al.* (*2021*), in 2010, almost half of all Hungarian households considered paying utility bills as a burden, while 7 per cent of the population faced the problem of energy poverty, i.e. a building with energy costs twice the median (*Koltai et al. 2021:14*). The Hungarian government and the MNB have put into place several forms of support to increase the energy efficiency of the housing stock, such as the Green Home Programme, the Home Renovation Programme, which can also be used to improve energy efficiency, the low-interest home renovation loan and the Green Mortgage Certificate (*Takarék Index 2022; Kandrács 2023; Nagy et al. 2021*).

2.3. The role of the energy crisis caused by the Russian-Ukrainian war

The Russian-Ukrainian war that started on 24 February 2022 has had numerous negative economic consequences. This is particularly true for the European Union, given its dependence on Russian energy imports, as energy prices in the region increased dramatically (*Csáki 2021*) before starting to decline. The 2022 energy crisis has thus highlighted the need for a new, more sustainable energy policy in European countries, as the unaffordable cost of gas and electricity poses a problem for the population (*Tóth et al. 2023*). In Hungary, a law on reducing utility costs was introduced in 2013[9] to reduce energy prices that had increased in the wake of the 2008 global economic crisis; it provided for a price cap on the universal retail prices of gas and electricity. This meant that even in the months after the war started, Hungarian citizens paid a fixed price for the energy they used, regardless of the market environment. However, the sudden price increases triggered by the Russian-Ukrainian war made the law on reducing utility costs unsustainable. Consequently, in July 2022, the law was amended. Since 1 August 2022, retail customers have been charged a higher fixed price for the portion of the annual average electricity and gas consumption in excess of the average consumption of 2,523 kWh for electricity and 1,728 m^3 for natural gas.[10] As a result, the Hungarian population was exposed to the effects of the energy crisis with a delay. However, this does not mean that the problem has been less severe than in other countries, partly because of the characteristics of an outdated housing stock (*Subsection 2.2*). *'The renewal of the housing stock, while achieving climate goals, may also improve resilience to a potentially prolonged energy crisis'* (*Takarék Index 2022:6*), as the majority of the Hungarian housing market is made up of properties built before the end of communism, and 80 per cent of households consuming more than 120 per cent of average household energy consumption are linked to such properties (*Tóth et al. 2023:134*). In such an environment, buyers may become more sensitive to the energy characteristics of properties, as confirmed by the MNB's estimated price index on residential mortgage transactions (*MNB 2023*). Interestingly, the price

[9] Act LIV of 2013 implementing the reductions in utility bills.
[10] Government Decree No. 259/2022. (VII. 21.) determining certain universal service tariffs.

index shows that the highest increase in the gap between i) residential properties solely relying on reduced-price energy, and ii) gas-heated residential properties with energy consumption above the reduced-price threshold occurred in 2022 Q4. The price index of the latter group fell by 1.3 per cent during the quarter, while the price index of the former rose by 1.2 per cent during the same period. Among the possible reasons for the delayed effect, the MNB suggests that sellers were only willing to reduce prices over time and as a result of reduced market liquidity.

3. Factors affecting house prices

Trends in the real estate market and the factors that influence real estate prices have long been the subject of research. The literature suggests that, in addition to macroeconomic factors, the individual characteristics of a property also have a major impact on its market value. Among other things, these include property characteristics (1), such as floor area and lot size, the number of rooms (*Lu et al. 2017*), the year of construction, type of house (detached, prefab, semi-detached, etc.), its comfort level (*Zietz et al. 2008*), and property amenities, such as a garage, basement and attic (*Herath – Maier 2010*). They also include the location of the property (2), such as its distance from town centres, schools and transport hubs (*Chow 2011*), potential environmental hazards, noise and air pollution (*Allen et al. 2015*), and energy characteristics (3), such as the characteristics of the cooling and heating system (*Ramos et al. 2015*). Recently, there has been an increasing focus on the relationship of house prices with the labour market (*Békés – Bisztray 2020*), regional differences (*Székely 2000; Banai et al. 2018*) and energy efficiency (*Ertl et al. 2021; Hajnal et al. 2022; Horváth et al. 2013*) in Hungary. The literature on the latter is summarised in the following subsection.

3.1. The relationship between energy performance certificates and house prices

The relationship between energy performance certificates and house prices has been studied in several countries, including Hungary. A summary of the results is shown in *Table 2*. The scaling and calculation methodology of energy performance certificates may differ between countries, making comparisons difficult (*Ertl et al. 2021*). Overall, the literature suggests that in most of the countries and periods studied higher energy ratings/better energy efficiency are reflected in higher house prices. Several factors may underlie the spatial variation in the impact of energy efficiency on house prices, such as the country's weather, the energy-efficiency characteristics of the housing stock, the temperature preferences of the population, climate awareness, etc. A detailed exploration of these factors, however, goes beyond the scope of this study.

In Germany, *Taruttis and Weber* (*2022*) investigated the relationship between energy efficiency and the sales value of properties between 2014 and 2018, using a sample of more than 400,000 observations; they found that a 100 kWh/m^2 reduction in specific energy demand leads to an average increase in real estate prices of 6.9 per cent. In terms of the Hungarian scale, this is roughly equivalent to the difference between the energy-inefficient and energy-efficient home groups relative to the average energy-efficiency group. *Hahn et al.* (*2018*) showed that the heating system has a significant explanatory power on the purchase price and rent of buildings, as 'green' systems are more overvalued than 'brown' systems that use fossil energy. In Ireland, *Stanley et al.* (*2016*), controlling for the year of construction and the type, size and location of properties, found that a 50 kWh/m^2 lower specific energy demand is associated with a 1.5 per cent higher market price, while a value 1 point higher on a 15-point energy performance certificate scale from G to A1 equals a 1 per cent higher property price.

Ramos et al. (*2015*) analysed the Portuguese real estate market in their research, measuring the role of energy performance certificates in relation to the D rating. Based on their results, the price of A-, B- and C-certified buildings is 6 per cent higher on average than that of D-certified houses. Properties with poorer energy efficiency (E, F or G) imply a 4 per cent lower price compared to average energy-efficiency buildings, which means that people are willing to pay a higher price for a better energy rated property. A study based on over 190,000 data points from the Welsh housing market (*Fuerst et al. 2016*) shows that prices for A and B category properties are 11 per cent higher than for houses with a D category energy performance certificate, while prices for C category properties are 2 per cent higher. Compared to the D label, the E, F and G labels are 2 per cent, 5 per cent and 7 per cent cheaper, respectively. Factors influencing Spanish property prices have been studied by, among others, *Marmolejo-Duarte – Chen* (*2022*), who found that when controlling for building quality and location parameters, a one-step higher energy performance certificate category corresponds to a 2 per cent higher price.

For the Norwegian housing market, there is no consensus in the literature on the price impact of energy efficiency. First, according to *Khazal – Sønstebø* (*2020*), for properties surveyed between 2010 and 2018, green-labelled buildings (A, B and C) offer a 6 per cent premium over buildings without an energy performance certificate, and an average price that is 6 per cent higher for an A energy-efficient building compared to the worst (G) category. On the other hand, according to *Olaussen et al.* (*2019*), energy efficiency or energy performance certificates do not play a significant role in the evolution of house prices. The quantitative result was supported by a questionnaire survey, which showed that buyers are not willing to pay a higher price for a building with better energy efficiency, as opposed to a better location, larger size or more rooms. Also in the Netherlands, *Murphy* (*2014*) found that there is only a weak relationship between energy performance certificates and house prices; similarly, observing the Italian real estate market, *Fragonard et al.* (*2017*) also found that there is no significant effect of energy performance certificates on house prices when controlling for the basic characteristics of the property.

In Hungary, three major studies have been carried out on this topic. The first of these, by *Horváth et al.* (*2013*), investigated the impact of energy renovation projects between 2004 and 2009: their results show that such renovations had a positive impact of 9.81 per cent on prices. *Ertl et al.* (*2021*) investigated the detached house segment and found that, controlling for location and building characteristics, houses with more modern energy use or houses that have undergone energy renovation feature a significant price premium. Buildings in categories AA–BB have significant explanatory power compared to all other categories. The most recent research on the newly-built housing project segment found that in Budapest, new-build houses with AA–BB energy performance certificate cost 5.1 per cent more on average than houses with a CC energy performance certificate (*Hajnal et al. 2022*).

Compared to the two articles on Hungarian data published in the past few years, our study covers a wider range of properties, i.e. not only detached houses or new-build properties in our unique database. By analysing the data, therefore, more general conclusions may be drawn. The other main contribution of the study is that it offers a unique way of looking at the energy crisis, which allows us to document changing preferences and relationships reflected in house prices.

Table 2
Summary of the literature to date

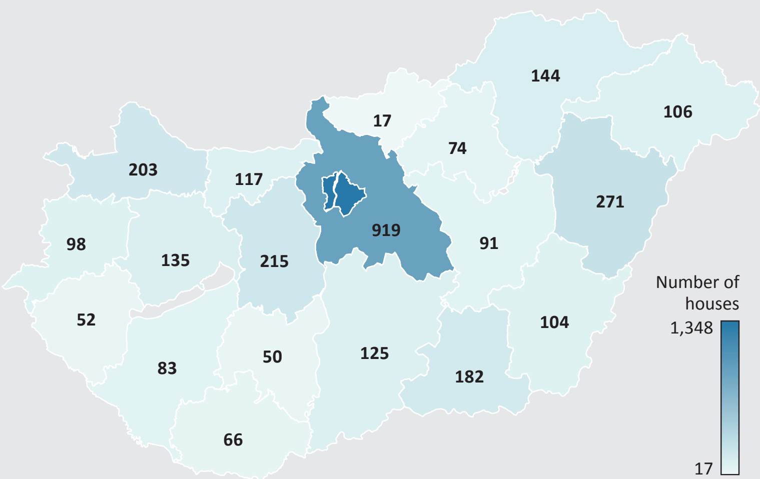
Country	Period under review	Author(s)	Result
Germany	2014–2018	*Taruttis – Weber (2022)*	A significant positive relationship exists between energy efficiency and house prices
	2015	*Hahn et al. (2018)*	Heating system has significant explanatory power for house prices
Ireland	2009–2014	*Stanley et al. (2016)*	A significant positive relationship exists between energy efficiency and house prices
Portugal	2015	*Ramos et al. (2015)*	A significant positive relationship exists between energy efficiency and house prices
Norway	2000–2014	*Olaussen et al. (2019)*	Energy demand and energy performance certificates have no significant impact on prices
	2011–2018	*Khazal – Sønstebø (2020)*	A significant positive relationship exists between energy efficiency and house prices
Netherlands	2013	*Murphy (2014)*	Energy performance certificates have only a moderate impact on house prices
United Kingdom	2003–2014	*Fuerst et al. (2016)*	A significant positive relationship exists between energy efficiency and house prices
Spain	2020	*Marmolejo-Duarte – Chen (2022)*	A significant positive relationship exists between energy efficiency and house prices
Italy	2011–2014	*Fregonara et al. (2017)*	Energy performance certificates have no significant impact on house prices
Hungary	2020	*Ertl et al. (2021)*	A significant positive relationship exists between energy efficiency and house prices
	2019–2021	*Hajnal et al. (2022)*	A significant positive relationship exists between energy efficiency and house prices
	2004–2009	*Horváth et al. (2013)*	Energy renovation significantly increases the value of the property

Note: Dark green indicates a strong positive relationship between energy efficiency and housing prices, light green shows a weak relationship and grey denotes no significant relationship.

4. Data and descriptive statistics

The study uses mortgage data from a commercial bank in Hungary. Properties that have been appraised for mortgage purposes in 2022 are included in the database, and additional property characteristics are available specifically for the energy use and energy performance certificates of the buildings. The database originally contained 5,137 observations, from which the data cleaning process removed properties with 0 estimated market value, or which were outliers based on studentised residuals, leverage values and Cook's distance test, resulting in a cleaned database of 4,400 observations. The properties are located in all parts of the country, except municipalities with less than 1,500 inhabitants. The spatial distribution is shown in *Figure 2*. Most properties are located in Budapest and Pest County, with the former accounting for 31 per cent of the total and the latter for 20 per cent of the data. On average, other counties accounted for 1–5 per cent of the database, with the lowest number of available data from Nógrád county, accounting for 0.4 per cent of data. According to the Hungarian Central Statistical Office, buildings in Budapest account for 21 per cent of Hungary's real estate stock, while properties located in Pest County account for half of that amount, i.e. 11 per cent.[11] Similarly to the sample data, 2–6 per cent of houses are located in other counties. This suggests that the majority of the sample is well matched to the overall Hungarian housing stock population. Central Hungary is, however, overrepresented, including, in particular, a high proportion of properties in Pest County.

Figure 2
Spatial distribution of sample data by county



Note: Number of houses in Budapest is 1,348.

[11] Source: HCSO: *Housing stock, housing density by county and by region, 1 January.* https://www.ksh.hu/stadat_files/lak/hu/lak0017.html. Downloaded: 4 April 2023.

While the data include all 12 categories of energy performance certificates used in Hungary since 2016, the number of buildings with AA++, AA+ and AA ratings is significantly lower than the other categories. Therefore, for ease of presentation, these categories are presented in aggregate. As the energy performance certificate is based on the amount and efficiency of energy use, it is worth checking the consistency of the data for reliability purposes.

The x-axis in *Figure 3* shows the primary energy use of the properties in the sample, which measures the energy use per square metre on an annual basis. The figure shows that the category of energy performance certificates neatly corresponds to the extent of primary energy use, with the majority of buildings with almost zero energy demand having the highest energy performance certificate, while those using more than 300 kWh of energy per year are assigned the worst classification – HH, II or JJ. As data on energy performance certificates normally become available through transactions and many have difficulty in interpreting a value in kWh/m^2/year, our analysis looks at the energy performance certificate categories rather than the value of the energy consumption of the property. Regarding the relationship between primary energy use and the price per square metre of the property, *Figure 4* shows that in accordance with our previous expectations properties with better energy efficiency and thus higher ratings are worth more on average than those with lower energy efficiency. The relationship between the two variables is illustrated by the dashed trend line in the figure, which shows a decreasing trend towards lower energy-efficient properties. The relationship between the energy performance certificate and the market price is examined formally later in the paper.

In 2022, 135,362 energy performance certificates were issued for properties in Hungary, according to the national electronic register of energy performance certificates.[12] Their distribution is presented in *Table 3*, which shows that nearly 30 per cent of the data belong to the best performance group (AA–BB and CC) in the study, 41 per cent of the data belong to the average category (DD–GG), and 29 per cent of the data belong to the worst performance group (HH–JJ). Examining the sample data, 37 per cent of the homes are in the highest energy-efficiency category (AA–CC), 44 per cent are in the average energy-efficiency category (DD–GG) and 19 per cent are in the energy-inefficient category (HH–JJ). The most frequent category in the sample and in the actual data is CC. The discrepancy in the distribution of the sample certificate data may be due to the higher share of properties built after 2010, which increases the number of AA–BB certificates.

[12] Source: https://entan.e-epites.hu/?stat_megoszlas

Figure 3
Relationship between specific energy demand and energy performance certificates

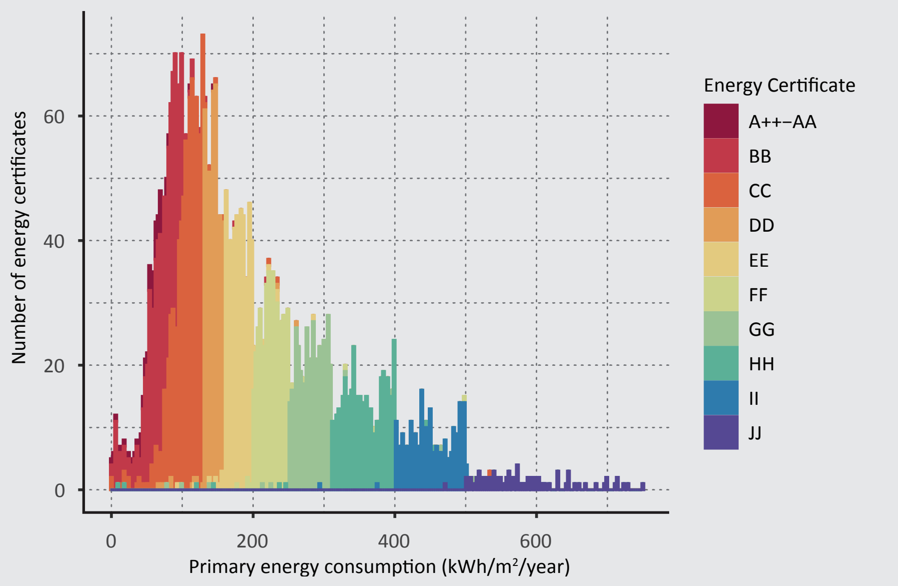


Figure 4
Relationship between energy performance certificates and estimated price per square metre

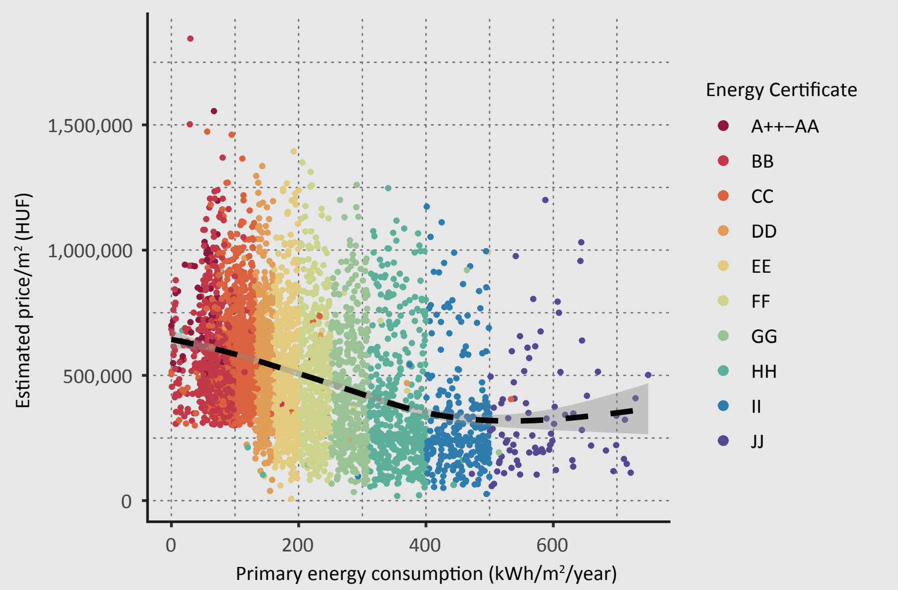


Table 3
Distribution of certificates issued in 2022 compared to the sample

	Actual distribution (%)	Sample distribution (%)
AA–BB	12.7	16.40
CC	16.6	20.32
DD	9.7	11.70
EE	10.3	12.60
FF	10.7	10.60
GG	10.7	9.60
HH	13.6	10.10
II	10.2	6.50
JJ	5.4	2.20

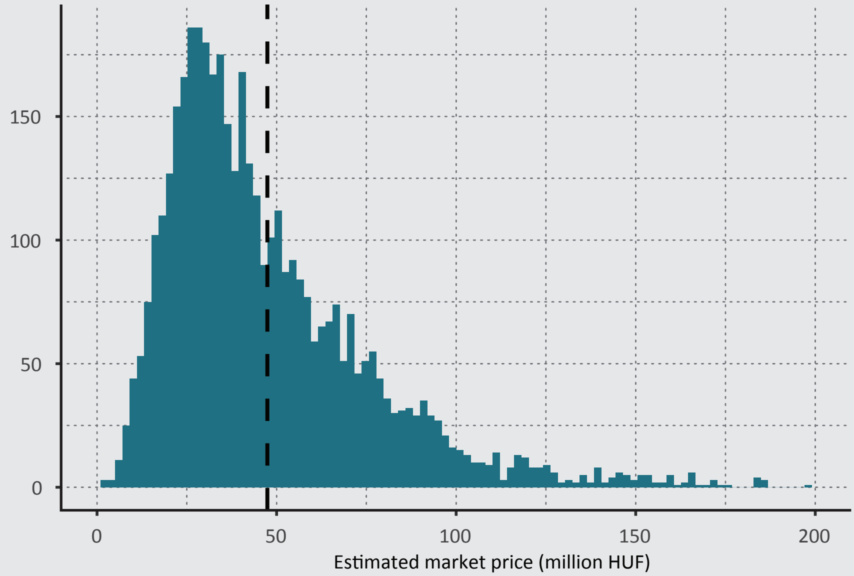
5. Methodology

The study uses the linear regression estimation methodology, which is often employed in the literature to investigate the relationship between house prices and energy performance certificates (*Ertl et al. 2021; Hajnal et al. 2022; Ramos et al. 2015; Stanley et al. 2016; Taruttis – Weber 2022*). In the regression model, we use a difference-in-difference estimation method to examine the effect of the energy crisis, as this methodology is suitable for estimating an impact based on changes over time (*Ramos et al. 2015*). The dependent variable of the model is the estimated market value of dwellings, while the explanatory variables include the energy performance certificate, the quarters of years and their interaction with the energy performance certificate and the control variables. The regression equation is as follows:

$$\begin{aligned} Y^{*} = \beta_0 + \beta_1 energy\ performance\ certificate + \beta_2 Q1 + \beta_3\, Q3 + \beta_4\, Q4 \\ + \beta_5\, Q3 \times energy\ performance\ certificate \\ + \beta_6\, Q4 \times energy\ performance\ certificate + control\ variables + \varepsilon, \end{aligned} \tag{1}$$

where β_0 is a constant representing the intersection of the regression line and the y-axis; β_1 is the coefficient of the energy performance certificate; β_2 is the coefficient of the first quarter; β_3 is the coefficient of the third quarter; β_4 is the coefficient of the fourth quarter; β_5 is the effect of the third quarter on the relationship between the energy performance certificate and house prices; β_6 is the effect of the fourth quarter on the relationship between the energy performance certificate and house prices; and ε stands for the error term. Based on the difference-in-difference method, the energy performance certificate multiplied by the quarters (Q3–Q4) shows how the price of buildings with a higher (AA–CC) or lower (HH–JJ) energy performance certificate changed during the quarter relative to buildings in the average energy performance category (DD–GG). In the interaction model, we compare to the second quarter of the year.

Figure 5
Histogram of the dependent variable of the model



Note: The dashed line shows the average value.

The dependent variable in the regression is the market value of the property, as estimated by the appraisers (*Y**), which is a noisy transformation of the actual price (*Y*).[13] Suppose $Y = Y^* + v$, where v is a normally distributed error term with the expected value 0. In this case, the regression coefficients β in the equation (1) will not be biased; however, the variance of the (composite) error term ($\varepsilon + v$) is larger than in a regression where the real price (*Y*) is the dependent variable.

The histogram of estimated market values is shown in *Figure 5*. The distribution of the variable is skewed left and elongated right, with a minimum value of HUF 600,000, a maximum value of HUF 401 million and a mean of HUF 48.5 million. It is presented in logarithmic form in the model for ease of interpretation. The explanatory variables of the estimate can be grouped into three categories. The explanatory variable considered in the model is the energy performance certificate, which is broken down into the three groups mentioned earlier: energy-efficient properties (AA–CC), average energy-efficiency properties (DD–GG) and energy-inefficient properties (II–JJ). The average efficiency category is the control group in the study. The additional control variables can be split into housing characteristics and variables focusing on geographical location. The continuous control variables are logarithmic in the model as in *Ramos et al.* (*2015*) and *Taruttis – Weber* (*2022*),

[13] Exact transaction data were not available. Mortgage lending is based on the appraisal process, which determines the size of the loan.

similarly to the dependent variable, while the year of construction is divided into five categories: 1880–1940, 1941–1980, 1981–2000, 2001–2010, and after 2010.

The comfort level is a three-degree scale, ranging from no comfort to full comfort, with 80 per cent of data falling into the latter category. Properties are broken down by type into two groups, i.e. detached houses and flats, which are represented in the sample roughly equally. The reason why we use the third and fourth quarter dummy variables in the interaction terms is that these are the time periods after the partial phase-out of the cuts in utility costs in Hungary. As the measure was announced by the government on 13 July 2022, just over two weeks before it was due to enter into force (*Government of Hungary 2022*), we do not expect a significant impact on prices before July.[14]

6. Descriptive regressions

This study examines whether the importance of energy performance certificates has increased in house prices since the start of the energy crisis in 2022. Before answering the research question, the paper builds a linear regression model to explain house prices and examines whether there is a relationship between energy efficiency and house prices over the sample period as a whole. It may indicate a problem with the data or the model if the results found are at odds with the literature or intuition. Two models are employed, which differ in that the first one uses certificates as individual categories, while the second one groups them together. Both models thus contain 4,400 observations and are considered significant by the global F-test. Based on the coefficient of determination, the first model explains 75 per cent of the variance of the dependent variable, while the second explains 74 per cent. In both models, the dependent variable is the logarithmic form of the estimated market value of the property, explained by 8 control variables in addition to the energy performance certificate, almost all of which are significant. The results are summarised in *Table 4*.

In the model, the effect of the explanatory variables is interpreted *ceteris paribus*, i.e. with all other variables held constant. For energy performance certificates, the worst (JJ) rating in the first model was used as the control group. *Figure 6* clearly shows that by including the individual categories of certificates, we can see a progressively higher property price from the worst category to AA–BB classification. All ratings apart from the bottom two categories (II, HH) were significant, with GG-certified properties costing 12 per cent more, FF buildings 21 per cent more and EE groups 23 per cent more on average compared to the worst-rated buildings. The DD category indicates a 25 per cent higher average price, the CC category 29 per cent higher, while AA–BB properties cost 35 per cent more on the property market compared to the JJ category. Looking at the difference between the adjacent

[14] We only have information for the month of the valuations.

categories, there are three places where a significant difference is observed: one level up from the HH mark, there is a 6 per cent difference in property prices; one level up from the FF mark, there is a 9 per cent difference on average, and there is a significant 7 per cent difference between the CC and AA–BB categories.

In the second model, the difference (compared to the first model) was due to the fact that the energy performance certificate categories were divided into three groups, with average energy-efficiency properties constituting the control group. Again, significant differences between groups were found, as illustrated in *Figure 7*. Compared to medium-rated (DD–GG) homes, energy-efficient home prices are 7 per cent higher on average and energy-inefficient homes are 17 per cent less expensive on average.

The results for the impact of energy performance certificates are consistent with other literature on the Hungarian housing market. *Hajnal et al.* (*2022*) found a 5 per cent price premium for energy-efficient properties compared to average-rated properties. Looking at individual energy performance certificate categories, *Ertl et al.* (*2023*) found that homes in the FF group are sold for a 20 per cent higher price compared to the worst-rated properties, while the best-rated category can have a premium of up to 52 per cent. This suggests that the issue of energy efficiency has not only become an important topic in public life, but also appears in the pricing of real estate, and thus it is worth considering these features when buying or renovating a home.

Figure 6
Estimated impact of energy performance certificates on house prices (individual values)

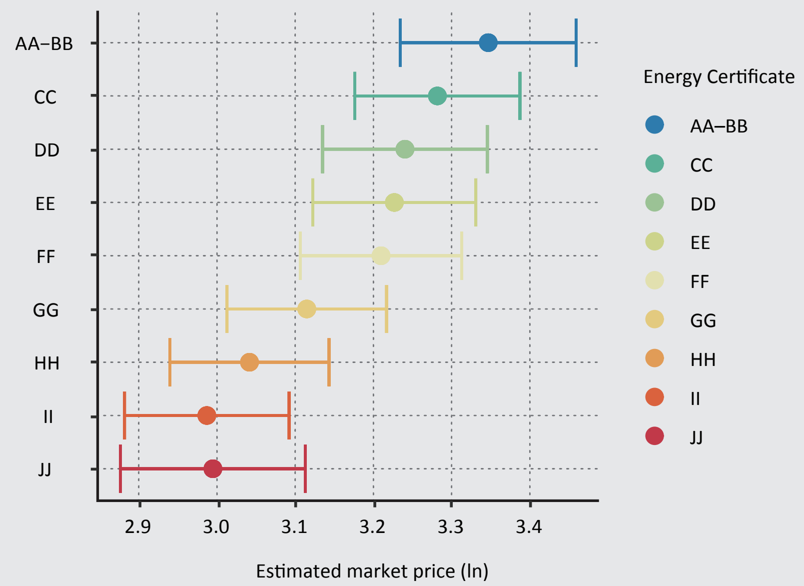
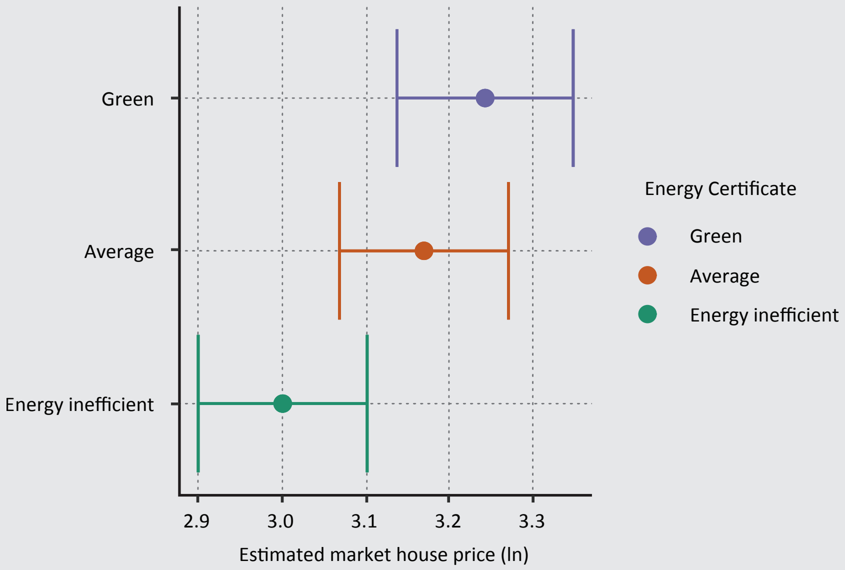


Figure 7
Estimated impact of energy performance certificates on house prices (grouped)



Most of the control variables were significant at a 5 per cent p-value, except for the distance from the town centre and the property type in the first model. In line with preliminary expectations, larger floor areas and a higher population (in the settlement) are associated with higher market values, while the estimated market value of a flat is 4 per cent lower on average than that of a detached house. Comparing buildings in terms of comfort level, it can be seen that, compared to houses without amenities, a full comfort level may amount to a property price up to 15–17 per cent higher. In terms of the year of construction, houses built between 2001 and 2010 cost 31–34 per cent more on average than properties in the earliest-built category. In terms of the regional location of buildings, the model shows a higher price for properties located in the South Great Plain compared to properties located in all other regions except Northern Hungary; however, this value was not found to be significant. According to the model, prices were 7–8 per cent higher in the third and fourth quarters compared to the first quarter, while there was no statistically significant price change in the second quarter of the year. This is somewhat different compared to the housing price index produced by the MNB. The aggregate nominal MNB house price index was 8 per cent, 6 per cent and 4 per cent higher in 2022 Q2, Q3 and Q4, respectively, compared to 2022 Q1.[15] In part, this discrepancy may be due to the fact that our sample does not contain estimation data from January 2022. Additionally, properties in Budapest are overrepresented in the sample, where prices rose above the national average for the year as a whole.

[15] Source: *MNB Housing Price Index.* https://statisztika.mnb.hu/idosor-2612. Downloaded: 7 April 2023.

Table 4
Comparison of linear regression models

Explanatory variables	(1) Unique ET values		(2) Grouped ET values	
	Coefficients	**P-value**	**Coefficients**	**P-value**
Energy performance certificate (control: JJ)				
II	–0.0077	0.8340	–0.1684	0.0000
HH	0.0467	0.1877		
GG	0.1200	0.0008	Control: DD–GG	–
FF	0.2149	0.0000		
EE	0.2319	0.0000		
DD	0.2455	0.0000		
CC	0.2870	0.0000	0.0729	0.0000
AA–BB	0.3520	0.0000		
Ln Base area	0.7498	0.0000	0.7549	0.0000
Year of construction (control: 1880–1940)				
1941–1980	–0.1036	0.0000	–0.0889	0.0000
1981–2000	0.1410	0.0000	0.1718	0.0000
2001–2010	0.3108	0.0000	0.3473	0.0000
2011–2020	0.2163	0.0000	0.2876	0.0000
Renovation (control: none)	0.0624	0.0000	0.0664	0.0000
Comfort level (control: Dwelling without comfort)				
Dwelling with some amenities	0.0742	0.0955	0.0749	0.0940
Dwelling with all amenities	0.1493	0.0007	0.1667	0.0000
Property type (control: detached house)	–0.0197	0.1682	–0.0360	0.0110
Region (control: Southern Great Plain)				
Southern Transdanubia	0.1102	0.0000	0.1145	0.0000
Western Transdanubia	0.2074	0.0000	0.2102	0.0000
Central Transdanubia	0.2566	0.0000	0.2588	0.0000
Central Hungary	0.4446	0.0000	0.4476	0.0000
Northern Great Plain	0.0295	0.1626	0.0318	0.1352
Northern Hungary	–0.0429	0.0946	–0.0446	0.0843
Ln Population size	0.0782	0.0000	0.0789	0.0000
Ln Distance from town centre	0.0007	0.8929	0.0011	0.8386
Q2 (dummy)	0.0107	0.5383	0.0141	0.4210
Q3 (dummy)	0.0703	0.0001	0.0744	0.0000
Q4 (dummy)	0.0753	0.0000	0.0805	0.0000
Number of items	4,400		4,400	
F-test	450.2		564.3	
R^2	74.7%		74.3%	

Note: The sample includes properties that were appraised for mortgage purposes in 2022, and additional property characteristics are available specifically for the energy use and the energy performance certificates of buildings. The data are for municipalities with more than 1,500 inhabitants. Standard errors are robust for heteroskedasticity.

7. The result of the interaction between the energy crisis and energy performance certificates

The main values of the regression model estimated from equation (1) for the energy crisis and energy performance certificates are summarised in *Table 5*. *Annex 1* contains the full interaction model presented in *Table 5*, as well as a version of the model in which the dependent variable is the property's price per square metre. As the main conclusions of the study are not affected by changing the dependent variable, the regression results with the estimated market value variable are presented below. The energy performance certificates were split into three groups in the model, with the control group being the average energy efficiency properties. The coefficient of variation of the energy performance certificate in this case may be interpreted as follows: the average cost of energy-efficient homes (energy-inefficient homes) in the sample before the regulation of utility costs was 8 per cent more (12 per cent less) than average energy-using buildings. Both coefficients are statistically significant. The variable beta value for Q3 indicates that the value of the average category of houses in 2022 Q3 was 9 per cent higher than in Q2, controlling for other factors, while the variable beta for Q4 indicates that the value of the average category of houses in 2022 Q4 was 8 per cent higher than in Q2.

Table 5
Result of linear regression on cross-effects

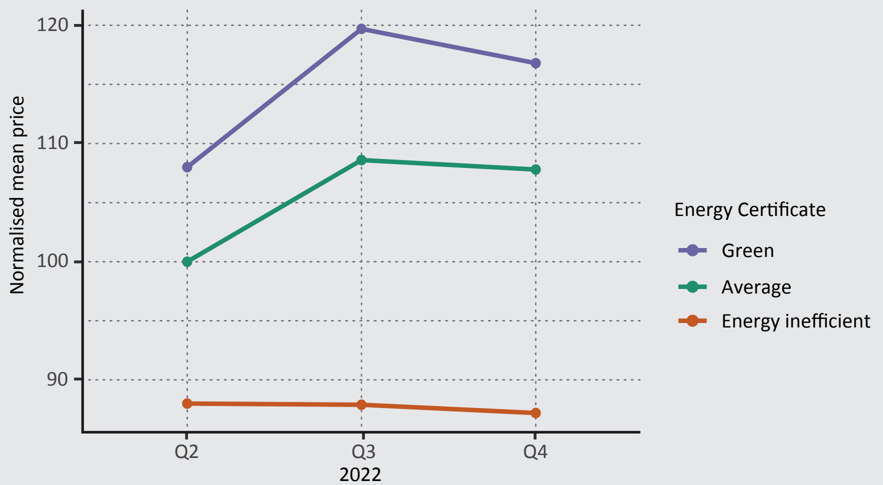
	Coefficients	P-value
Energy performance certificate (control: DD–GG)		
Energy-efficient homes (AA–CC)	0.0782	0.0000
Energy-inefficient homes (HH–JJ)	–0.1175	0.0000
Quarter (control: Q2)		
Q1	–0.0169	0.3347
Q3	0.0861	0.0000
Q4	0.0786	0.0000
Q3 x Energy performance certificate		
Energy-efficient homes (AA–CC)	0.0316	0.2400
Energy-inefficient homes (HH–JJ)	–0.0850	0.0115
Q4 x Energy performance certificate		
Energy-efficient homes (AA–CC)	0.0090	0.7128
Energy-inefficient homes (HH–JJ)	–0.0862	0.0042
Number of items	4,400	
F-test	479.1	
R^2	74.4%	

Note: The sample includes properties that were appraised for mortgage purposes in 2022, and additional property characteristics are available specifically for the energy use and the energy performance certificates of buildings. The data are for municipalities with more than 1,500 inhabitants. Other controls in the model include the floor area, year of construction, comfort level, region, population, distance from the town centre and a dummy which stands for a renovated property. Standard errors are robust for heteroskedasticity.

The effect of the interaction of the two variables is illustrated in *Figure 8*. In both quarters, the regression estimation yielded statistically significant results only for properties classified as HH–JJ when examining the interaction of the two variables. In the present case, this may be interpreted as the fact that in the first half of the year, an energy-inefficient property cost, on average, 12 per cent less than an average energy rated property after controlling for other effects, while in the period after the onset of the energy crisis, the difference is 20 per cent (–11.75%+–8.5% in Q3 and –11.75%+–8.6% in Q4). Similarly, when looking at the relative value of energy-efficient homes, it is found that before the residential energy price increase they were worth, on average, 8 per cent more than average energy-efficiency homes in Q2, while after the energy crisis the difference is 11 per cent (7.8%+3.1%) in Q3 and 9 per cent (7.8%+1%) in Q4, although the second coefficient is not statistically significant in either case. The statistically *non-significant* difference seen in the higher energy performance group compared to the average group may be explained by the fact that the best category is largely achieved only by new-build homes. These were priced very high due to high construction costs (*Bereczki et al. 2022*), among other things, and it is possible that demand in this category acted as a barrier to any further significant price increase.

The combined effect is shown in *Figure 8*. Adding up the coefficients of the quarters and the interaction terms, we find that after the energy crisis the value of the best-category houses increased by 12 per cent in the third quarter of the year, while the value of the worst-category houses did not increase, despite an average increase in house prices. In the fourth quarter, the value of houses in the best category wase 9 per cent higher, on average, than in the second quarter (before the onset of the energy crisis), while the value of houses in the worst category was 1 per cent lower.

Figure 8
Changes in house prices based on the estimated coefficients of the model



Note: Indices, average energy-efficiency property in Q2 = 100, which is used as the benchmark for Q3 and Q4.

8. Limitations

The main limitation for the conclusion of the study is the identification of the energy crisis. While we believe that the most significant event for the value of energy performance certificates was the restructuring of the utility cost reduction, rumours of an energy crisis were circulating even before July, which means that we cannot rule out the possibility that it was already present in property valuations before that date. This would bias the interaction coefficients (of the energy performance certificates and post-energy crisis time periods) investigated in this study towards zero. It is also possible that different submarkets priced the impact of a potential utility cost price shock differently. For example, if buyers of energy-efficient homes rely on better information, that submarket may have experienced stronger re-pricing before July, which would result in a higher bias (towards zero) for the best energy performance certificates and the third/fourth quarter interaction terms compared to other interaction terms. It is important to note here that in this study, market processes are only reflected in the data through the intermediation of appraisers.

The study uses the identification assumption that other events unrelated to the energy crisis had no impact on the relative value of energy performance certificates after July.

In the absence of a longer time series, it is not possible to check the extent of the correlation of the movement of prices of different energy classes in the past. Was the separation of prices in our study typical in the past? Going back to the beginning of 2021, the MNB's Housing Market Report shows that the price index for i) gas-heated mortgaged properties with energy consumption above the cut-off threshold for utility prices and ii) for mortgaged properties consuming reduced-priced energy only, moved together during 2021 and early 2022, and only diverged during 2022 (*MNB 2023*).

Another limitation of the study is that not all data were available for the control variables of the regression model (e.g. number of bathrooms, distance from school/grocery store, etc.). The impact of quantified energy performance certificates may therefore include the impact of other factors, such as the external appearance of the property.

The impact of the 2022 energy crisis on energy performance certificates has not yet been studied in the literature in this form, which may be due in part to the fact that the problems related to energy security and volatility of energy prices have yet to be resolved. We believe that, despite the short timeframe, it is worth investigating at an early stage, since the results show that the real estate market is expected to undergo significant shifts in energy use, including energy performance certificates. The fact that the energy crisis has had a significant negative impact on house prices for buildings with below average energy efficiency is in line with the results of research in Hungary that show that energy modernisation plays a major role in the pricing of the property market.

9. Summary

The study examines the relationship between house prices and energy performance certificates in Hungary, with a particular focus on the impact of the changes in utility prices in the early months of the energy crisis. The issue is particularly topical in the light of the energy crisis caused by the Russian-Ukrainian war in 2022 and the global climate crisis. Our results are based on a unique database of mortgage data from a commercial bank in Hungary. By investigating the effect of an unexpected shock, the study brings us closer to understanding the causal relationship between energy performance certificates and house prices. Most of the available literature has taken a different approach. Our data cover a wide range of property types and the entire territory of the country. The study uses linear regression estimation similar to previous research in the literature.

In line with international literature and the results of studies on individual segments of the Hungarian residential real estate market, the energy performance certificates of real estate explain the house price in 2022 in a statistically and economically significant manner. The better the rating of a home, the higher its price. On a 12-point scale, a GG rating means an average of 12 per cent higher value compared to the worst category (JJ), while the highest rating (AA–BB) translates into a 35 per cent higher property value when controlling for other factors. Examining the energy performance certificates as three separate groups, energy-efficient homes (AA–CC) yield a 7 per cent higher price compared to average-rated (DD–GG) properties, while energy-inefficient buildings (HH–JJ) cost 17 per cent less on average. Examining the interaction of the 2022 energy crisis with certificates, it can be observed that before the energy crisis an energy-inefficient property cost, on average, 12 per cent less than an average energy-rated property when controlling for other impacts, with this difference rising to 20 per cent in the period after the onset of the energy crisis (Q3 and Q4). The relative value of energy-efficient homes shows that before the energy crisis hit in August 2022 such dwellings were worth, on average, 8 per cent more than average energy-efficient homes in Q2, while after the energy crisis, this difference increased to 9–11 per cent.

The results of the research relate to the early stages of the energy crisis and can therefore be taken as an indication. The study shows that energy performance certificates are priced by the market and their role has grown since the energy crisis began. For Hungary, the market also shows that it is increasingly important to increase the energy efficiency of the housing stock. A large proportion of Hungarian properties were built before the end of communism and do not reach the required level of energy efficiency or do not have a heating system that can effectively protect them from the increased utility costs caused by the energy crisis. The modernisation of the building stock is not only important at level of individuals in order to maximise profits, but also at the government level, based on considerations related to sustainability and energy dependence. In the future, it may be worthwhile to establish a unified framework for promoting energy efficiency in housing, including precise targets and the means of implementation and support needed to achieve them.

This study serves as a basis for further research and as a preparatory work for policy decisions. Another important question may be how much of an incentive homeowners have to upgrade to energy efficiency given the current pricing of energy efficiency in the housing market, and how incentives can be most effectively and efficiently increased. A possible broader energy modernisation scheme would not only reduce costs for the population, but would also ensure progress towards climate goals by developing systems using renewable energy sources.

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Annex

Annex 1
A full interaction model for the original variable and the dependent variable log (price/m²)

Explanatory variables	(1) Interaction		(2) Interaction (price/m²)	
	Coefficients	P–value	Coefficients	P–value
Q1 (control: Q2)	–0.0169	0.3347	–0.0154	0.4253
Q3 (control: Q2)	0.0861	0.0000	0.0920	0.0000
Q4 (control: Q2)	0.0786	0.0000	0.0898	0.0000
Energy performance certificate (control: DD–GG)				
Energy-efficient homes (AA–CC)	0.0782	0.0000	0.1139	0.0000
Energy-inefficient homes (HH–JJ)	–0.1175	0.0000	–0.0912	0.0000
Q3 x Energy performance certificate				
Energy-efficient homes (AA–CC)	0.0316	0.2400	0.0407	0.1683
Energy-inefficient homes (HH–JJ)	–0.0850	0.0115	–0.1072	0.0038
Q4 x Energy performance certificate				
Energy-efficient homes (AA–CC)	0.0090	0.7128	0.0058	0.8294
Energy-inefficient homes (HH–JJ)	–0.0862	0.0042	–0.0935	0.0048
Ln Base area	0.7544	0.0000	–	–
Year of construction (control: 1880–1940)				
1941–1980	–0.0885	0.0000	–0.0990	0.0000
1981–2000	0.1727	0.0000	0.0514	0.0441
2001–2010	0.3477	0.0000	0.2314	0.0000
2011–2020	0.2875	0.0000	0.1669	0.0000
Renovation (control: none)	0.0663	0.0000	0.0788	0.0000
Comfort level (control: Dwelling without comfort)				
Dwelling with some amenities	0.0814	0.0688	0.0813	0.0986
Dwelling with all amenities	0.1714	0.0001	0.0855	0.0774
Property type (control: detached house)	–0.0359	0.0109	–0.2649	0.0000
Region (control: Southern Great Plain)				
Southern Transdanubia	0.1137	0.0000	0.0733	0.0144
Western Transdanubia	0.2094	0.0000	0.1996	0.0000
Central Transdanubia	0.2586	0.0000	0.2187	0.0000
Central Hungary	0.4469	0.0000	0.4094	0.0000
Northern Great Plain	0.0324	0.1266	0.0380	0.1036
Northern Hungary	–0.0446	0.0835	–0.0710	0.0123
Ln Population size	0.0790	0.0000	0.0888	0.0000
Ln Distance from town centre	0.0009	0.8646	–0.0116	0.0567
Number of items	4,400		4,400	
F-test	479.1		305.4	
R^2	74.4%		64%	

Note: The sample includes properties that were appraised for mortgage purposes in 2022, and additional property characteristics are available specifically for the energy use and the energy performance certificates of buildings. The data are for municipalities with more than 1,500 inhabitants. Other controls in the model include the floor area, year of construction, comfort level, region, population, distance from the town centre and a dummy which stands for a renovated property. Standard errors are robust for heteroskedasticity.