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**Working Paper**

## Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter?

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# Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter?

HEMF Working Paper No. 04/2020

*by*

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August 2020

UNIVERSITÄT  
DUISBURG  
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*Open-Minded*



Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter? by Lisa Taruttis and Christoph Weber

## Abstract

The German government aims at a climate-neutral building stock by 2050 to reach the goals defined in the Climate Action Plan 2050. Increasing the energy efficiency of existing buildings is therefore a high priority. For this purpose, investments of private homeowners will play a major role since about 46.5% of the German dwellings are owner-occupied. To identify potential monetary benefits of investing in energetic retrofits, we investigate whether energy efficiency is reflected in property values of single-family houses in Germany. Thereby we examine possible heterogeneous effects among regions. With 455,413 individual observations on a 1km<sup>2</sup>-grid level for 2014 to 2018, this study adds to the literature 1) by examining the effect of energy efficiency on housing values for Germany on a more small-scale level and specifically investigating regional disparities in this context and 2) by estimating an energy efficiency value-to-cost ratio. Applying a hedonic analysis, we find a positive relationship between energy efficiency and asking prices. We also find evidence for regional disparities. Effects are significantly weaker in large cities compared to other urban areas, whereas the impact in rural areas is much stronger. Since property values are expected to decline in rural regions, homeowners could alleviate this development by increasing the energy efficiency of their dwellings.

Keywords : Energy efficiency; residential buildings; regional disparities; German housing market; hedonic analysis; housing value

JEL-Classification : C31, Q40, R21, R31

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# 1 Introduction

In Germany, about 35% of final energy consumption as well as about one third of CO<sub>2</sub> emissions are related to the building sector<sup>1</sup> (Federal Ministry for Economic Affairs and Energy, 2015). According to the Energy Efficiency Strategy for Buildings (ESG), the German government aims at a climate-neutral building stock by 2050 to reach the goals defined in the Climate Action Plan 2050 (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2016). Doubling the rate of energetic building refurbishments from approximately 1% to 2% per annum is needed for this purpose since most buildings that will exist in 2050 are already built. In order to try to speed up this process, a new bill has been voted by the German parliament in June 2020, which aims at unifying the national energy standards for buildings (WEKA Redaktion, 2020). This German Energy Act for Building (GEG, 2019) regroups the former Energy Savings Act (EnEG, 2013), the Energy Saving Regulation (EnEV, 2015) and the Renewable Energy Heat Act (EEWärmeG, 2008) and is thus intended to be less bureaucratic, more balanced and easier to understand.

Newly constructed buildings already have to meet the standards for nearly zero-energy houses, but a large number of existing dwellings in Germany still display poor energetic conditions. Increased energy efficiency of buildings can therefore be enhanced considerably through energy efficient retrofits. Investments of private homeowners will play a major role here since about 46.5% of all dwellings are owner-occupied (Destatis, 2019). Nonetheless, especially for residents living in their own single-family houses, investments for energetic refurbishments might seem to be too large compared to their monetary benefits. Example calculations indicate payback periods up to 22 years, with a mean payback period yet clearly below the typical service life of most components (Holm et al., 2015).

While savings due to less energy consumption are relatively predictable, there is still a lack of comprehensive evidence on returns to investments in energy efficiency for the German real estate market. Cajias and Piazzolo (Cajias and Piazzolo, 2013) find a 0.015% increase in a building's total return if energy consumption decreases by 1%, using 2,630 observations obtained from the German Investment Property Databank (IPD). For the German rental market, Cajias et al. (Cajias et al., 2019) find that energy efficient rental units are also rented at a premium. Kholodilin et al. (Kholodilin et al., 2017) compare the capitalization of energy efficiency in selling prices and rents for the Berlin housing market and also find positive effects.

To identify potential monetary benefits for private homeowners when they invest in refurbishments for a better energy performance of their buildings, we investigate whether energy efficiency is reflected in the property value of single-family houses in Germany. We apply a hedonic regression to a repeated cross-sectional dataset that contains individual housing observations as well as socio-economic data on a 1km<sup>2</sup>-grid level. Furthermore, we examine possible heterogeneous effects among regions and additionally compare potential monetary benefits with initial investment costs as well as annual energy cost savings using a tailored nonlinear least squares estimator.

This study therefore adds to the previous literature 1) by examining the effect of energy efficiency on housing values for Germany on a more small-scale level and specifically investigating regional disparities in this context and 2) by estimating an energy efficiency value-to-cost ratio by comparing the increase in housing value to the expected costs for energy efficiency improvements. Contrary to most studies that use Energy Efficiency Ratings reported by the building's Energy Performance Certificates (EPCs) as measure of efficiency, we use the final energy consumption given in those EPCs to get more accurate results.

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<sup>1</sup> depending on delimitation.

The remainder of this paper is organized as follows. Chapter 2 gives an overview of previous research in this field at the intersection of energy, housing and regional economics. Chapter 3 explains the econometric approach before Chapter 4 describes the underlying datasets and reports different descriptive statistics. Empirical results follow in Chapter 5 and Chapter 6 concludes.

## 2 Previous research

Already more than thirty years ago, Dinan and Miranowski (Dinan and Miranowski, 1989) investigated whether fuel savings resulting from energy efficient retrofits are capitalized into housing prices. Using a hedonic price model for the Des Moines, Iowa housing market, they found evidence for positive effects of energy efficiency on real estate values in this area. In a European context, Brounen and Kok (Brounen and Kok, 2011) were among the first to report evidence on a price premium for green labeled dwellings in residential markets in the Netherlands. Furthermore, Kok and Jennen (Kok and Jennen, 2012) evaluated financial implications of energy efficiency in the Dutch market for commercial real estate and also found positive effects on rents for A-, B- or C-labeled buildings.

Various studies for different European countries followed, e.g. Hyland et al. (Hyland et al., 2013) for the Irish real estate and rental market, Högberg (Högberg, 2013) and Cerin et al. (Cerin et al., 2014) for single-family houses in Sweden, Fuerst et al. (Fuerst et al., 2015) for sale prices of residential properties in England, as well as Fuerst et al. (Fuerst et al., 2016b; Fuerst et al., 2016a) for residential markets in Wales and Finland. Other studies also investigated the impact of energy efficiency on housing values in southern European countries, for example Ramos et al. (Ramos et al., 2015) for Portugal and Ayala et al. (Ayala et al., 2016) for Spain. All studies found a positive impact of energy efficiency on real estate prices of about 2% to 10% as well as up to 4% for rental markets.

In contrast to many European countries, the German residential market has a high share of rented accommodations. Against this background, a recent study by Cajias et al. (Cajias et al., 2019) investigates the effect of energy efficiency on rental values using a sample of more than one million observations across 403 local markets for the time period 2013 to 2017 in Germany. Furthermore, the study examines the link between energy ratings and the time-on-market. Results suggest that energy efficient apartments are rented at a premium and that efficient dwellings are more liquid due to shorter marketing periods compared to their inefficient counterparts. The study is limited to newly built apartments as well as recently renovated flats that are advertised as “like new”.

Nevertheless, the ownership rate in Germany still accounts for about 46.5% so that the impact of energy efficiency on real estate values is also of particular interest for homeowners. Up to date and to our knowledge, there is no study investigating these effects comprehensively throughout Germany. Therefore, our paper is going to fill this gap. Moreover, we also provide a detailed comparison of the value increase to observed costs for energy efficiency improvements using a novel nonlinear regression model specification. In contrast to Cajias et al. (Cajias et al., 2019), our study focuses on existing buildings in all conditions.

## 3 Econometric approach

In order to identify effects of energy efficiency on prices for single-family houses in Germany, we estimate a hedonic pricing model in the sense of Lancaster (Lancaster, 1966), Rosen (Rosen, 1974) and Brown and Rosen (Brown and Rosen, 1982) to control for price differences caused by quality differences other than the energy consumption. We use a common semi-logarithmic

specification, where the logarithmized price per square meter living space of dwelling  $i$  in neighborhood  $k$  and municipality  $m$  at time  $t$  is described by the following equation:

$$\ln PRICE_{i,km,t} = \alpha + \beta ENERGY_i + \gamma \mathbf{D}_i + \delta \mathbf{N}_{kt} + \mu_t + \tau_m + \varepsilon_{ikmt} \quad (1)$$

The main variable of interest –  $ENERGY_i$  – describes the specific energy consumption for heating of dwelling  $i$ , measured in kWh/m<sup>2</sup>a. Information about the heating system as well as a dummy that indicates whether warm water consumption is included in  $ENERGY_i$  or not, are covered by vector  $\mathbf{D}_i$ . This vector also includes different hedonic characteristics, such as logarithms of living space and lot size, age of the dwelling and number of rooms together with different factor variables that indicate condition and quality of the object.

$\mathbf{N}_{kt}$  describes the structure of the dwelling's neighborhood based on 1km<sup>2</sup>-grid cells. The vector consists of different socio-economic characteristics, for example population size, logarithmized purchasing power per capita and unemployment rate and also contains information about the predominant building type within the neighborhood.

Finally,  $\mu_t$  are time dummies for 2015 to 2018 (with reference group 2014),  $\tau_m$  are regional fixed effects on municipality level and  $\varepsilon_{ikmt}$  is the error term of the regression reporting cluster-robust standard errors to correct for spatial and temporal correlation between subdivisions (Cameron and Miller, 2015). An overview of the complete set of control variables is given in Table A1.

We firstly estimate a simple semi-logarithmic regression model  $\ln Price = \alpha + \beta ENERGY + \varepsilon$ . Since we will not only focus on the impact of energy efficiency on housing prices but also on regional disparities, we add interactions in two ways:

- (a) *EastWest*: East Germany<sup>2</sup> in comparison to West Germany, and
- (b) *DTYPE*: district types, i.e. urban areas ("städtische Kreise") in contrast to independent large cities ("kreisfreie Großstädte"), densely populated rural areas and sparsely populated rural areas.

The definition of these district types is based on an indicator for different regional types according to their settlement structure at NUTS3 level, which is provided by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2019). The spatial distribution of these district types is shown in Figure 1. ANOVA testing indicates that statistically significant differences between the groups are present for both typologies ( $F=797.66$ ,  $p<0.001$  for *EastWest* and  $F=1138.6$ ,  $p<0.001$  for *DTYPE*) and we hence can assume that disparities among regions exist regarding the effect of energy efficiency on single-family house prices.

We secondly estimate the regression as described by Eq. (1) and successively interact the whole RHS of the model with both regional factor variables *EastWest* and *DTYPE* as described by Eq. (2) using ordinary least squares. We expect the coefficients for  $ENERGY$  to be negative as we include energy consumption in our regression. In our context of energy efficiency, a higher level of consumption is thus associated with less efficient buildings. Due to the semi-logarithmic specification, the coefficients for  $ENERGY$  can be interpreted as semi-elasticities and therefore give us the monetary surplus in approximately  $100 \cdot |\beta|$  percent for a one unit decrease in energy consumption. We also run different subsample regressions to check the robustness of our results, e.g. by controlling for housing shortage.

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<sup>2</sup> Included are dwellings located in Berlin, Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt and Thuringia. In a second regression, we excluded Berlin.



$$\ln PRICE_{i,km,t} = (\alpha + \beta ENERGY_i + \gamma D_i + \delta N_{kt} + \mu_t + \tau_m) \cdot \left\{ \begin{matrix} EastWest \\ DTYPE \end{matrix} \right\} + \varepsilon_{ikmt} \quad (2)$$

To compare the increase in housing value with energy cost savings due to higher energy efficiency, we additionally estimate a second model as given by Eq. (3) and Eq. (4) using a nonlinear least squares estimator. We thereby again use robust standard errors to control for heteroskedasticity.

$$\ln(PRICE_{i,kt} + \tilde{\beta} ENERGY_i) = \tilde{\alpha} + \tilde{\gamma} D_i + \tilde{\delta} N_{kt} + \mu_t + \varepsilon_{ikt} \quad (3)$$

$$\Leftrightarrow PRICE_{i,kt} = -\tilde{\beta} ENERGY_i + \exp(\tilde{\alpha} + \tilde{\gamma} D_i + \tilde{\delta} N_{kt} + \mu_t + \varepsilon_{ikt}) \quad (4)$$

This model directly reflects the fact that energy consumption translates (almost) proportionally<sup>3</sup> into operating costs for the house. In a total cost of ownership perspective, we hence expect energy consumption to contribute linearly to housing cost (left hand side of Eq. (3)). The coefficient  $\tilde{\beta}$  is now expected to be positive – the lowering impact on housing prices in Eq. (4) is contained in the negative sign obtained after rearrangement of the terms. This coefficient  $\tilde{\beta}$  can directly be interpreted as monetary impact on total cost of ownership in Euro per one unit decrease in energy use, since both housing prices and energy consumption are normalized to the square meters of living space. In this cost-based perspective,  $\tilde{\beta}$  reflects the average price per unit of energy multiplied by a present value of annuity factor. This multiplier may be determined using Eq. (5) and describes the monetary surplus in housing value per one Euro decrease in annual energy costs.

$$energy\ multiplier = \frac{\tilde{\beta}}{average\ energy\ price\ for\ heating} a \quad (5)$$

Using this multiplier, we can easily compare investment costs that are needed for a specific amount of energy cost savings with the increase in housing values. At the same time, the values obtained for this energy multiplier may be compared to rent multipliers which are frequently used by practitioners to assess prices for rented buildings.

## 4 Data

Our dataset combines micro-level information on prices and characteristics of buildings with population and neighborhood characteristics on a 1 km<sup>2</sup>-grid level. Those grid areas are assigned either to West or East Germany or to four different district types, as shown in Figure 1. *Large cities* are defined as independent cities with more than 100,000 citizens. *Urban areas* describe districts with a population density larger than 150 inhabitants per square kilometer as well as districts, where more than half of the population lives in middle-sized or large (non-independent) cities<sup>4</sup> that have a population density above 150 inh/km<sup>2</sup> as well. In contrast, districts with a population share above 50% in middle-sized or large (non-independent) cities and a population density

<sup>3</sup> Small non-linearities may occur due to degressive heating fuel prices or through higher efficiencies of larger heating systems. Yet price changes and efficiency improvements will hardly exceed small single-digit percentages.

<sup>4</sup> Medium-sized cities are defined in German statistics as cities with a population between 20,000 and 99,999 whereas large cities have more than 100,000 inhabitants Bundesinstitut für Bau-, Stadt- und Raumforschung (2019).

lower than 150 inh/km<sup>2</sup>, as well as districts with a population share below 50% in middle-sized or large cities that have a population density of minimum 100 inh/km<sup>2</sup>, are described as *densely populated rural areas*. All other districts are characterized as *sparsely populated rural areas* (see (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2019) for a detailed description).

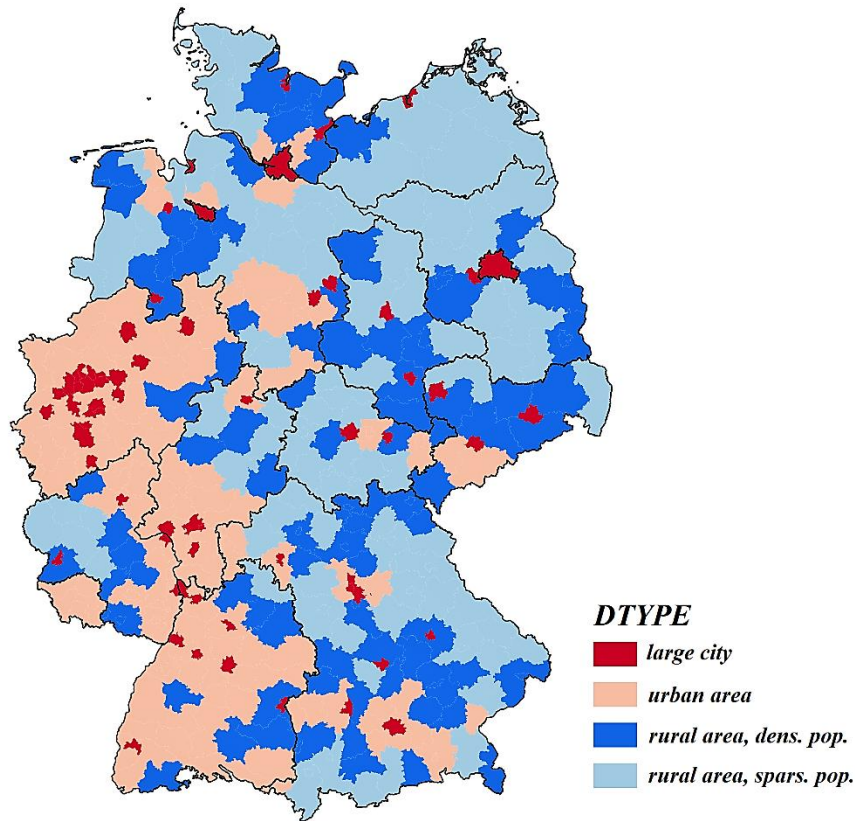


Figure 1 Regional distribution of district types in Germany  
Own illustration based on INKAR. Map Data: @GeoBasis-de/BKG 2019.

## 4.1 Building data from ImmobilienScout 24

Information on prices and characteristics of residential houses are extracted from the RWI-GEO-RED dataset (B. Boelmann et al., 2019), which is based on data provided by the internet platform ImmobilienScout24 (IS24). The data is available from 2007, but as we are interested in energy efficiency, we restrict the dataset to advertisements which were placed from May 2014. We use this specific cutoff, because on May 1, 2014, a new revision of the Energy Saving Regulation (EnEV, 2015) came into effect which made the declaration of the energy performance certificate for buildings obligatory for sellers. By restricting the dataset this way, we diminish the probability of selection bias<sup>5</sup>.

Furthermore, we remove outliers based on the 1<sup>st</sup> and 99<sup>th</sup> percentiles of asking price, living space and lot size and also exclude all observations with missing values for main variables, e.g. energy consumption, asking price and living space. For all factor variables that indicate condition etc., we add the level “unknown” for missing values so as not to lose too many observations due to

<sup>5</sup> Before it was obligatory to declare the energy performance of the dwelling in the advertisement, it is likely that only sellers of efficient buildings placed information about this in their offers Frondel et al. (2020); Kholodilin et al. (2017).

control variables. We focus on existing single-family houses that were constructed between 1800 and 2010 and are neither used as holiday homes nor already let.

Although our data includes no information about final transaction prices, there are several reasons to assume that it is suitable in case of our analysis. With about 1.2 million new advertisements per month, ImmobilienScout24 is the biggest internet platform for real estate offerings in Germany with a self-reported market share of about 50% of all offered dwellings for sale or rent (Georgi and Barkow; Meulen et al., 2014). In addition, roughly 4.5 million users visit the website monthly and search for property in a high number of object exposés, provided by 70,000 private suppliers and 40,000 real estate commercials.

Moreover, Dinkel and Kurzrock (Dinkel and Kurzrock, 2012) examined whether asking prices quoted on IS24 are significantly higher than real transaction prices for owner-occupied dwellings. Using six districts of Rhineland-Palatinate as a case study, they found confirming evidence for this question, but differences between those prices do not vary systematically among property types. A uniform or stochastic yet uncorrelated mark-up on transaction prices, however, will not affect estimation results in any case when estimating a hedonic pricing model (Bauer et al., 2015).

Nevertheless, one way to control for the accuracy of asking prices is to add advertisement durations to the estimation model. Presumably the longer the duration, the higher will be the difference between asking price and real transaction price and vice versa (Dinkel and Kurzrock, 2012). To avoid measurement errors that may be connected to long durations<sup>6</sup>, we exclude all offers which were online for more than 1.5 years. We also clear the data from duplicates and only keep the last offering per object in the sample since it is assumed to represent the transaction price most closely.

In context of investigating effects of energy efficiency, one minor disadvantage comes along with the RWI-GEO-RED data. Information about the main energy source used for heating as well as primary energy consumption are missing. Nonetheless, the dataset also brings two major advantages. First, final energy consumption (final energy demand, respectively) is given and can be used instead of Energy Efficiency Ratings. Second, information about the type of the Energy Performance Certificate are included, which allows a better comparability of those values. EPCs based on energy consumption measures, i.e. so-called “consumption certificates” (Verbrauchsausweis), show about 25% lower values in comparison to EPCs based on a (calculated) “energy requirement” (Bedarfsausweis) (Verbraucherzentrale, 2018). The data also indicates whether energy used for warm water consumption is included in the given final energy consumption measure. We are therefore able to control for variation due to different EPCs.

## **4.2 Socio-economic data from microm Micromarketing-Systeme and Consult GmbH**

Socio-economic characteristics on a 1km<sup>2</sup>-grid level are taken from the RWI-GEO-Grid dataset (RWI and microm, 2020), which is based on data provided by microm Micromarketing-Systeme and Consult GmbH – a market research firm specializing in regional analysis (microm-Micromarketing-Systeme und Consult GmbH, 2019). Our dataset includes number of inhabitants as well as total purchasing power, unemployment rate, share of households with foreign household head and number of cars per household. We also use information about the predominant building type within a grid cell to describe the neighborhood in which an offered dwelling is located. Data is available from 2009 to 2017 and is merged to the housing data with a one-year lag. Thus, our final sample includes 455,413 observations from May 2014 to December 2018 distributed over 71,536 grid cells.

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<sup>6</sup> Zuehlke Zuehlke (1987) argues that whereas the probability of sale may be expected to increase over time due to diminishing reservation prices, buyers may also interpret longer durations as longer time paths of reservation prices. They may then expect the seller to reduce the price in case of an even longer duration, which will decrease the probability of sale (see also Neumann and Taruttis (2018)).

### 4.3 Descriptive statistics

Energy efficient houses are, on average, more expensive than inefficient ones, but at the same time, they are mostly younger, probably in a better overall condition and might have a newer heating system or other special features. Figure 2 shows the relationship between asking prices, energy efficiency and age of dwellings. The height of the bars describes the average price per square meter, the colors indicate the Energy Efficiency Ratings and the black line shows the mean object age. In our sample, an average “D”-rated single-family house, for example, was constructed in the 1980s, has a mean energy consumption of 116 kWh/m<sup>2</sup>a and is offered for 2,108 Euro per square meter living space.

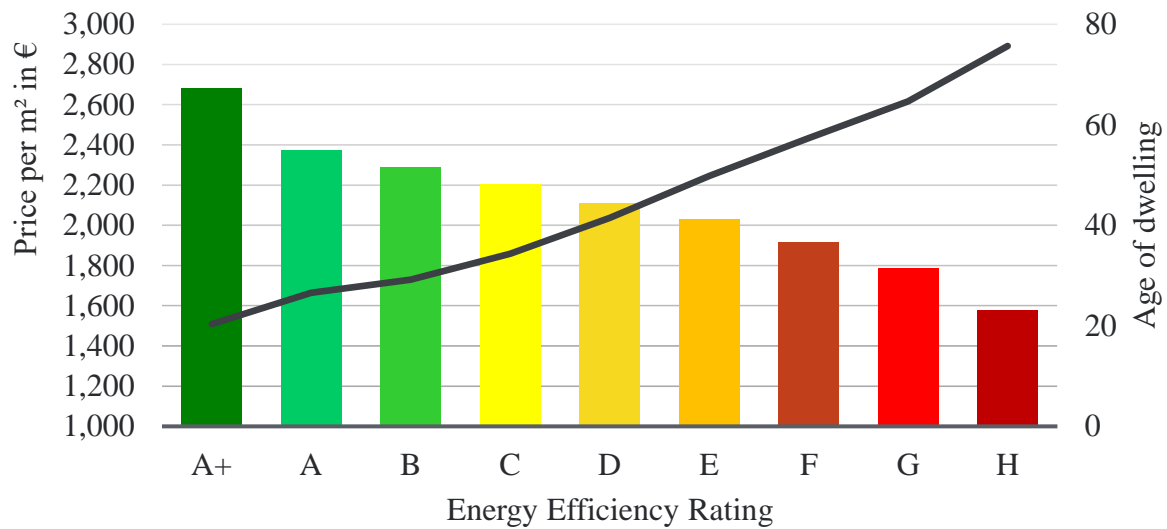


Figure 2 Average asking price and age by category of the Energy Efficiency Rating  
Authors' calculation and illustration based on IS24 and microm.

Table 1 gives an overview of summary statistics for main hedonic and socio-economic variables included in our regression model. The median dwelling in our dataset has a final energy consumption for heating of 152 kWh/m<sup>2</sup>a, which corresponds to the upper end of an E-rating; average energy consumption even corresponds to an F-label. Prices range from 196 to 6,500 Euros per square meter of living space, which serves as a strong indicator for a mixed portfolio of advertisements that includes dwellings of all price classes. In our sample, the average dwelling is offered for 1,972 Euros per square meter which is mostly related to E-rated objects.

When looking at socio-demographic characteristics – especially at the maximum population density of 21,753 – it is important to remember that these information are given per 1km<sup>2</sup>-grid cell and that uninhabited grids are ignored. Average population density per squared kilometer amounts to 1,665 inhabitants; the minimum is 10 (due to data privacy reasons). The mean purchasing power per capita in our dataset amounts to 23,245 Euros, but with a minimum of slightly above 10,000 Euros and a maximum of more than 60,000 Euros, we see that huge differences between grid cells exists.

Table 1 Descriptive statistics of main variables

Variable	N	Mean	SD	Min	Max	Median	unit
<b>PRICE</b>	455,413	1,972	1,033	196	6,500	1,793	€/m <sup>2</sup>
<b>ENERGY</b>	455,413	169	88	5	600	152	kWh/m <sup>2</sup> a
<b>AGE</b>	437,989	52	31	10	220	46	2020 = 1
<b>LIVINGSPACE</b>	455,413	157	55	62	400	145	m <sup>2</sup>
<b>LOTSIZE</b>	450,790	711	499	75	3,476	609	m <sup>2</sup>
<b>ROOMS</b>	455,383	6	2	1	25	5	
<b>HITS</b>	455,413	2,344	2,712	1	350,316 <sup>a</sup>	1,570	
<b>ADV.DURATION</b>	455,413	1.71	2.06	0.03	18.30	1.00	months
<b>POPULATION<sup>b</sup></b>	455,413	1,665	1,616	10	21,753	1,154	inh/km <sup>2</sup>
<b>PURCH.POWER<sup>c</sup></b>	454,691	23,245	3,965	10,222	62,327	22,651	€/inh
<b>UNEMPL.RATE</b>	455,413	5.01	3.25	0.00	37.48	4.37	%
<b>FOREIGN</b>	455,413	6.82	5.82	0.00	77.78	5.44	%
<b>CARS</b>	455,413	1.15	0.25	0.07	6.27	1.17	cars/household

Authors' calculation based on IS24 and microm.

<sup>a</sup> Two observations with extreme high numbers of hits were excluded from the regression based on Cook's Distance ( $D > 0.005$ ).

After clearing the sample, the maximum number of hits is 146,144.

<sup>b</sup> avg. number of inhabitants per 1km<sup>2</sup>-grid cell. Only inhabited grid cells are included in the calculation, which is why the numbers are much higher than population densities measured at city or any larger level.

<sup>c</sup> measured as total purchasing power per 1km<sup>2</sup>-grid cell divided by total population per 1km<sup>2</sup>-grid cell.

An overview of summary statistics grouped by different regional factors is given in Table 2. Roughly half of all advertised dwellings in our sample are located in urban areas, whereas the other half is almost evenly distributed over large cities as well as densely and sparsely populated rural areas. While no major differences among area types arise in terms of energy consumption for heating, object age and living space, dwellings located in rural areas include, on average, a much larger lot size but are also much cheaper than those located in urban areas and large cities.

Comparing East to West Germany, average energy consumption in the latter is about 25 kWh/m<sup>2</sup>a higher, which is equivalent to roughly one category worse in the Energy Efficiency Rating. It is therefore surprising that dwellings in East Germany are, on average, four years older. Not surprisingly, however, is the perceptibly higher purchasing power of inhabitants of large cities in contrast to all other district types as well as in West compared to East Germany. Total population per grid cell is also higher in the western part of the country, which is in line with East Germany being mostly defined as rural (except some state capitals, e.g. Berlin, Dresden).

One main factor, that is directly related to energy efficiency, is the installed heating system. Houses that use heat pumps are, on average, the most efficient dwellings in our sample, while heating by stove leads to highest energy consumption measures followed by oil and night storage heating (cf. Table A2). However, improvements in energy efficiency are visible for retrofitted dwellings of all construction periods (cf. Table A3). In our dataset, about one-fourth of all advertised dwellings were renovated after 2000 and evidence suggests that at least in some cases sustainable energy systems, such as solar panels, wood pellet heating or heat pumps, were installed during modernization.

Another factor, that is at least indirectly related to the energy efficiency measure, is the type of the Energy Performance Certificate. In our sample, buildings with consumption certificates (Verbrauchsausweis) are on average 43 years old, while those certified based on requirement certificates (Bedarfsausweis) were built approximately 16 years earlier. Thus, our data matches legal requirements for different types of EPCs in Germany.

Consumption certificates are only permitted for buildings, that are either built from 1977 onwards, already meet the (EnEV) Heat Insulation Ordinance of 1977 (e.g. due to renovations) or have more than five residential units (which is not the case when looking at single-family houses).



Newly constructed houses<sup>7</sup> as well as older dwellings, that do not meet the 1977's Heat Insulation Ordinance, need a requirement certificate. Dwellings that are certified by consumption display an average energy consumption of 130 kWh/m<sup>2</sup>a, whereas those certified by requirement show a mean energy demand of 205 kWh/m<sup>2</sup>a. Here again, our data is consistent with the statement of the consumer association (Verbraucherzentrale, 2018) that consumption certificates report a significantly lower energy consumption than requirement certificates. In our sample, about 53% of all buildings are certified by requirement; the other 47% are certified by consumption.

Table 2 Main hedonic characteristics for different subsamples - mean values (standard deviations in parentheses)

	<i>DTYPE</i>				<i>EastWest</i>	
	large city	urban area	rural area, dens. pop.	rural area, spars. pop.	East	West
<b>No. of obs.</b>	74,947	225,702	84,176	70,588	53,720	401,693
<b>%</b>	16.46	49.56	18.48	15.50	11.80	88.20
<b>PRICE</b>	2,694 (1,118)	2,010 (971)	1,644 (880)	1,476 (825)	1,821 (1,123)	1,992 (1,018)
<b>ENERGY</b>	166 (83)	173 (89)	170 (89)	162 (87)	149 (84)	172 (88)
<b>AGE</b>	53 (29)	51 (30)	52 (33)	51 (34)	55 (39)	51 (30)
<b>LIVINGSPACE</b>	154 (56)	160 (55)	155 (55)	154 (54)	145 (53)	159 (55)
<b>LOTSIZE</b>	553 (389)	659 (453)	810 (540)	932 (593)	862 (606)	691 (480)
<b>POPULATION<sup>a</sup></b>	3,116 (2,210)	1,656 (1,402)	1,043 (1,015)	893 (931)	1,388 (1,768)	1,702 (1,591)
<b>PURCH.POWER<sup>b</sup></b>	24,800 (4,456)	23,905 (3,918)	21,989 (3,262)	20,7968 (2,743)	21,300 (3,419)	23,504 (3,960)

Authors' calculation based on IS24, microm and INKAR. SD in parentheses.

<sup>a</sup> avg. number of inhabitants per 1km<sup>2</sup>-grid cell. Only inhabited grid cells are included in the calculation, which is why the numbers are much higher than population densities measured at city or any larger level.

<sup>b</sup> measured as total purchasing power per 1km<sup>2</sup>-grid cell divided by total population per 1km<sup>2</sup>-grid cell.

## 5 Empirical results

Table 3 presents main results for regressions given by Eq. (1) and Eq. (2). Only estimates of interest are shown. Full hedonic regression results are available upon request; although, we find expected outcomes for all intrinsic housing characteristics. Besides OLS results (columns labelled (1) to (3)), we also report results with fixed effects at municipality level (columns (4) to (6)).

As expected, we find negative effects of energy consumption on asking prices for single-family houses. These effects are statistically significant in all specifications. Estimates can be interpreted as semi-elasticities. If energy consumption decreases [and energy efficiency therefore increases] by 1 kWh/m<sup>2</sup>a, the price per square meter for single-family houses in Germany increases, on average, by 0.083% (see column (1)). The effect of energy efficiency on house prices is 0.027 percentage points higher in East compared to West Germany. That means, if energy efficiency of dwellings located in East Germany increases by one unit, the asking price per square meter increases by 0.105% (see column (2)).

<sup>7</sup> The regulation is effective from May 2014, so dwellings that were built after this date are defined as “newly constructed”.

Table 3 Main regression results for the first model

	OLS				FE	
	(1)	(2)	(3)	(4)	(5)	(6)
<b>ENERGY</b>	-8.3e-04*** [1.9e-05]	-7.8e-04*** [1.9e-05]	-7.8e-04*** [2.6e-05]	-6.9e-04*** [1.1e-05]	-6.6e-04*** [1.1e-05]	-6.4e-04*** [1.5e-05]
<b><u>East/West (reference: West Germany)</u></b>						
<b>ENERGY:East</b>		-2.7e-04*** [6.9e-05]			-2.1e-04*** [4.4e-05]	
<b><u>district types (reference: urban area)</u></b>						
<b>ENERGY:city</b>			3.3e-04*** [4.6e-05]			2.9e-04*** [3.5e-05]
<b>ENERGY:dens</b>			-1.7e-04*** [5.1e-05]			-2.3e-04*** [2.9e-05]
<b>ENERGY:spars</b>			-3.3e-04*** [5.5e-05]			-2.8e-04*** [3.3e-05]
<b>Time FE?</b>	yes	yes	yes	yes	yes	yes
<b>Spatial FE?</b>	no	no	no	yes	yes	yes
<b>Adj. R-squared</b>	0.63	0.64	0.66	0.81	0.82	0.82
<b>Observations</b>	450,149	450,149	450,149	450,149	450,149	450,149

Note: Cluster-robust standard errors in brackets. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

The colon indicates an interaction between the two variables. All regressions include variables for structural and neighborhood characteristics. Columns (1) and (4) were estimated for the complete sample without interactions (see Eq. (1)), while columns (2) and (5) include the East/West interaction and (3) and (6) the district type interaction (as shown in Eq. (2)). Spatial FEs are on municipality level. Full regression results are available upon request. Authors' calculations based on IS24, microm and INKAR.

The effect of energy efficiency on asking prices for single-family houses among the four defined district types, holding everything else constant at mean level, is shown in Figure 3. In independent large cities, the effect is about 0.033 percentage points weaker compared to urban areas, while we find 0.017 and 0.033 percentage points stronger effects in densely and sparsely populated rural areas, respectively (see column (3) in Table 3). Different slopes indicate these diverse effects and ANOVA testing again supports the importance of differentiating among regions with  $F = 128.13$ ,  $p < 0.001$  for model (2) and  $F = 170.64$ ,  $p < 0.001$  for model (3).

When including municipality fixed effects, we are able to control for some omitted variables. Direction and significance of our results do not change, but overall, we find slightly lower effects as well as standard errors, which are about one-third smaller in size compared to those of the OLS model. In both specifications, the explanatory power of our model is quite strong: the FE-specification explains 82% of variation in our sample while OLS at least explains about two-thirds.

## 5.1 Subsample regressions

In order to understand the effects of energy efficiency on housing prices, we estimate different subsample regressions. First, we split our sample according to the type of Energy Performance Certificate since this is indirectly linked to the performance of a building (cf. 0). Results are shown in Table 4.

The impact of energy efficiency on real estate prices in the subsample of dwellings with requirement certificates is approximately twice the size of the effects in the other subsample. One explanation for such differences could be the fact that energy consumption listed in consumption certificates heavily depends on individual behavior of former inhabitants, that may or may not be indicative of the expected energy costs. This uncertainty is then reflected in a lower willingness to pay for energy efficiency. When looking into regional disparities, we see same pattern as in our baseline equations, with only one exception: in the consumption subsample, we find slightly

stronger effects for sparsely populated than for densely populated rural areas; however, those effects are statistically insignificant.

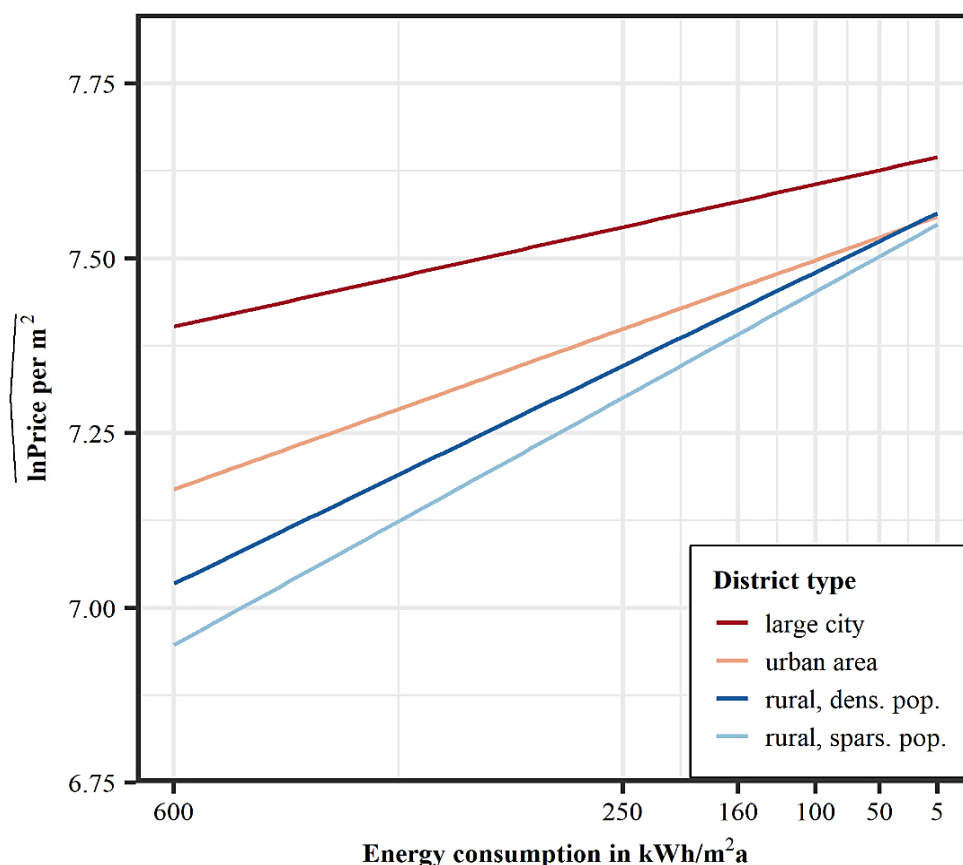


Figure 3 Effect plot: Energy consumption on fitted values among district types

Authors' calculation and illustration based on IS24, microm and INKAR. The plot is related to model (3) of Table 3 and shows the effect of energy consumption on the fitted values for the logarithmized price per m² of living space, holding everything else constant. One step on the x-axis refers to two steps in the Energy Efficiency Rating: 5 to 50 kWh/m²a corresponds to an A+ or A rating; 50 to 100 kWh/m²a corresponds to an B or C rating and so on. The last step from 250 to 600 kWh/m²a corresponds to G-rated dwellings.

Table 4 EPC subsample regression results

	Type of EPC			
	consumption certificate	requirement certificate	consumption certificate	requirement certificate
<b>ENERGY</b>	-4.4e-04*** [3.8e-05]	-9.2e-04*** [2.4e-05]	-4.4e-04*** [4.4e-05]	-8.7e-04*** [3.3e-05]
<b><u>district types (reference: urban area)</u></b>				
<b>ENERGY:city</b>			2.8e-04*** [7.1e-05]	3.1-e04*** [5.8e-05]
<b>ENERGY:dens</b>			-1.9e-04* [1.1e-04]	-1.3e-04** [6.0e-05]
<b>ENERGY:spars</b>			-1.7e-04 [1.1e-04]	-3.6e-04*** [7.1e-05]
<b>Time FE?</b>	yes	yes	yes	yes
<b>Spatial FE?</b>	no	no	no	no
<b>Adj. R-squared</b>	0.61	0.65	0.64	0.67
<b>Observations</b>	212,242	237,907	212,242	237,907

Note: Cluster-robust standard errors in brackets. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1.

The colon indicates an interaction between the two variables. All regressions include variables for structural and neighborhood characteristics. Columns (1) and (2) show results for Eq. (1), while columns (3) and (4) include the district type interaction as shown in Eq. (2). Authors' calculations based on IS24, microm and INKAR.



Furthermore, differences in market conditions probably impact effect sizes for the defined district types. Living space is already becoming scarce in wealthier urban regions in particular. We thus control, whether the weaker effects of energy efficiency on real estate prices in large independent cities are mainly driven by these shortages. To do so, we define market supply as advertisements per inhabitants based on district level and year. 2014 is excluded because of fewer included months and therefore fewer overall advertisements.

The advertisement-to-inhabitant ratio is, indeed, the lowest in large cities. On average, 0.0014 advertisements per inhabitant are available online. One reason might be that the overall share of single-family houses in large independent cities is quite lower than in other regions. In urban areas, approximately 0.0026 advertisements per resident are online. The numbers of advertisements per inhabitant in densely and sparsely populated rural areas, however, exceed the previous numbers by far and amount to 0.0034 and 0.0037, respectively. The distribution of market supply among regions is shown in Figure A1. Using quantiles  $Q_{1/3}$  and  $Q_{2/3}$ , three subsamples are generated by building terciles based on market supply. Results for these subsample regressions are shown in Table 5.

Table 5 Main regression results for market supply subsamples

	market supply					
	1 <sup>st</sup> tercile	2 <sup>nd</sup> tercile	3 <sup>rd</sup> tercile	1 <sup>st</sup> tercile	2 <sup>nd</sup> tercile	3 <sup>rd</sup> tercile
<b>ENERGY</b>	-6.9e-04*** [2.7e-05]	-8.1e-04*** [2.7e-05]	-9.6e-04*** [3.7e-05]	-7.4e-04*** [4.0e-05]	-7.2e-04*** [3.1e-05]	-8.4e-04*** [5.1e-05]
<b><u>district types (reference: urban area)</u></b>						
<b>ENERGY:city</b>				2.9e-04*** [5.4e-05]	3.6e-04*** [1.0e-04]	3.9e-04** [1.9e-04]
<b>ENERGY:dens</b>				-2.2e-04** [9.4e-05]	-2.4e-04*** [6.8e-05]	-2.3e-04*** [8.0e-05]
<b>ENERGY:spars</b>				-2.4e-04** [1.1e-04]	-3.9e-04*** [8.9e-05]	-3.0e-04*** [8.7e-05]
<b>Time FE?</b>	yes	yes	yes	yes	yes	yes
<b>Spatial FE?</b>	no	no	no	no	no	no
<b>adj. R-squared</b>	0.61	0.60	0.61	0.65	0.63	0.63
<b>Observations</b>	127,155	125,775	124,611	127,155	125,775	124,611

Note: Cluster-robust standard errors in brackets. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1.

The colon indicates an interaction between the two variables. Variables for structural and neighborhood characteristics are included. Authors' calculations based on IS24, microm and INKAR.

In the 1<sup>st</sup> tercile-subsample (with low market supply), we find weaker effects of energy efficiency on asking prices than in the 2<sup>nd</sup> tercile with medium and the 3<sup>rd</sup> tercile with high market supplies (see columns (1)-(3)). Statistically significant differences among regions within these subsamples still remain. The effect of energy efficiency on housing prices is weaker in large independent cities than in urban areas for all subsamples. Differences between densely and sparsely populated rural areas almost disappear in the 1<sup>st</sup> tercile subsample but remain in the 2<sup>nd</sup> and 3<sup>rd</sup>. Nonetheless, these results need to be interpreted with appropriate care. For example, the average market supply in urban areas in the 1<sup>st</sup> tercile subsample is 0.0016 while the average for large cities amounts to 0.0013. Therefore, different effect sizes may still be driven by differences in market conditions.

Including an interaction term between our main variable of interest and the advertisement-to-inhabitant ratio in our regression also suggests that bad market conditions have positive impacts on the effect size of energy efficiency on housing prices. If market supply increases, the coefficient of energy consumption decreases which results in increasing impacts of energy efficiency on

housing prices (see Table 6). More precisely, energy efficiency matters more if market conditions are worse. Therefore, the hypothesis that housing shortage has a detrimental effect on the energy efficiency effect size can be confirmed.

Table 6 Impact of market supply on the effect size

	<b>Germany</b>
<b>ENERGY</b>	-3.5e-04*** [4.3e-05]
<b>market supply</b>	-17.01*** [2.894]
<b>ENERGY:market supply</b>	-0.1691*** [0.0162]
<b>Adj. R-squared</b>	0.64
<b>Observations</b>	377,541

Note: Cluster-robust standard errors in brackets. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1.

The colon indicates an interaction between the two variables. Variables for structural and neighborhood characteristics are included. Authors' calculations based on IS24, microm and INKAR.

Since market supply was slightly decreasing over our sample period, we now compare the relative impact of energy efficiency across time, focusing on 2014 to 2018. The courses among regions are shown in Figure 4. In large cities and densely populated rural areas, the effect size was increasing from 2014 to 2017 and decreasing again from 2017 to 2018. The effect size was decreasing in urban areas as well, although the downward trend began a year earlier. An almost continuous upward trend can only be found in sparsely populated rural areas. However, in all regions we see stronger effects in 2018 compared to 2014, even though market conditions were slightly better in the latter. This trend might be explained through increasing environmental awareness, so that, in case of this hypothesis being true, we would expect even stronger effects over the next years since ecological attitudes and behaviors have gained importance in our society.

## 5.2 Monetary benefit vs. investment costs

Our results suggest that investments in energy efficient retrofits generate monetary benefits and that effects are heterogeneous among regions. But how large is the expected surplus compared to investment costs? In November 2019, the German Federal Government has passed the federal funding for efficient buildings ("Bundesförderung für effiziente Gebäude") (Klimakabinett der Bundesregierung, 2019). With this regulation, up to 20% of investment costs for energy efficient retrofits are tax deductible over three years<sup>8</sup>, so that with investment costs of up to 40,000 Euros, the taxable income can be reduced by up to 8,000 Euros.

Nonetheless, large parts of these costs still remain. For example, a complete refurbishment of a single-family house, which generates energy savings of about 60%, can be realized with investments of 277 Euros per square meter living space (co2online gemeinnützige GmbH). In our sample, a 60% reduction of mean energy consumption is equal to average energy savings of approximately 100 kWh/m<sup>2</sup>a with a needed investment of about 43,200 Euros or 2.77 Euros per annual kWh saved.

<sup>8</sup> Status November 2019.

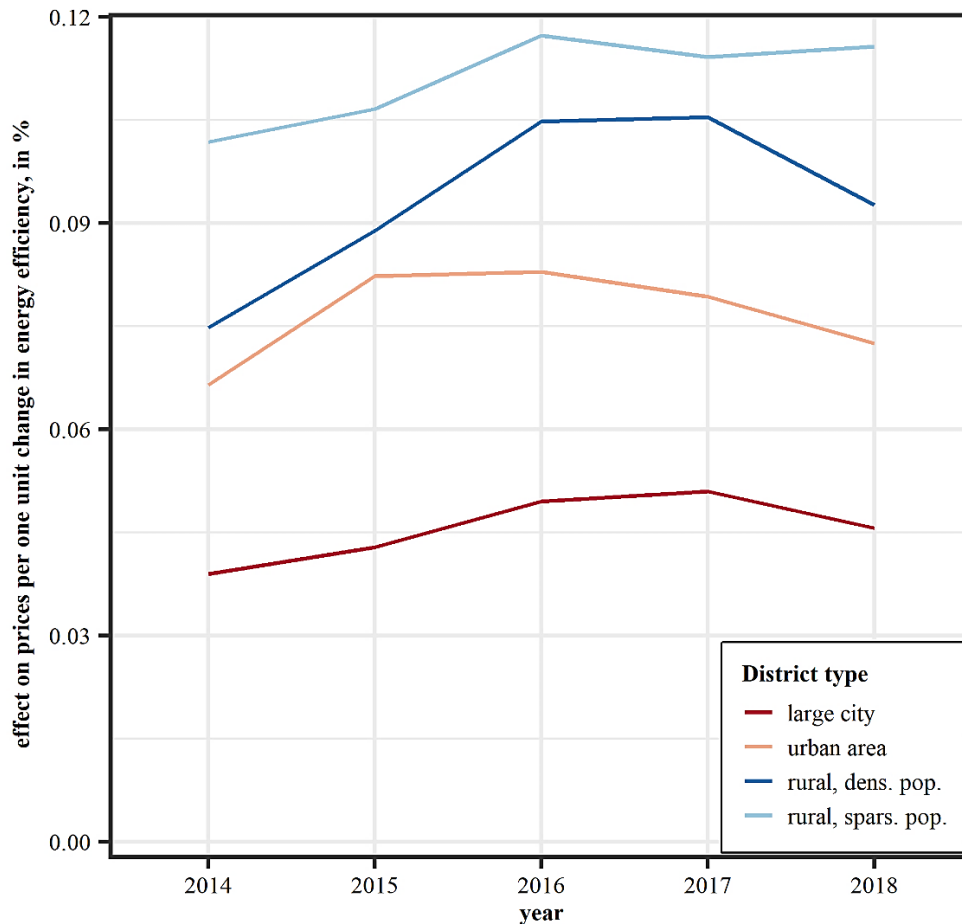


Figure 4 Impact of energy efficiency across time  
Authors' calculation and illustration based on IS24, microm and INKAR.

Table 7 shows main results for the nonlinear least squares estimation (Eq. (4)) as well as the corresponding energy multiplier (Eq. (5)) that can be used to calculate the monetary surplus per one Euro decrease in annual energy costs. We assume the mean energy price for heating to be 0.065 €/kWh (cf. (Federal Ministry for Economic Affairs and Energy, 2020)) when calculating the multiplier. Results can be interpreted as follows. If energy consumption decreases by one unit (kWh/m<sup>2</sup>a), the asking price for single-family houses located in large cities increases by 1.32 €/m<sup>2</sup>. The monetary benefit per one Euro decrease per square meter in annual energy costs is then given by 1 €/m<sup>2</sup>a\*20.34 a = 20.34 €/m<sup>2</sup>. The computed energy multiplier is in the same range as the rent multiplier indicated in recent market reports (cf. (DZ BANK AG, 2019)).

In general, relative values offer a better comparison among regions. However, when it comes to comparing the monetary surplus with existing investment costs, it is better to consider absolute values. The minimum (average) surplus that can be obtained is 1.32 Euros, when the dwelling is in large cities. In urban areas, the monetary surplus amounts, on average, to 1.55 Euros. In contrast to the OLS specification, where strongest effects are found in rural areas, the monetary surplus in rural regions here lies between those in cities and those in urban areas. This analysis thus nuances Model 1 in that the relative importance of *ENERGY* increases when we are in rural areas, but the absolute impact reduces. When comparing West and East Germany, we still see stronger effects in the latter (not shown here).

Table 7 Regression results for the second model with corresponding multipliers

	NLS			
	large city	urban area	dens. pop.	rural area spars.pop.
<b>ENERGY</b>	1.3222*** [0.0482]	1.5457*** [0.0200]	1.4841*** [0.0312]	1.4069*** [0.0303]
<b># iterations to convergence</b>	6	5	5	6
<b>Achieved convergence tolerance</b>	1.442e-06	6.269e-06	2.478e-06	2.855e-06
	corresponding multiplier			
	20.34	23.78	22.83	21.64

Note: Robust standard errors in brackets. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1.

Variables for structural and neighborhood characteristics, as well as year-dummy variables are included. Subsamples were used for estimation. Authors' calculations based on IS24, microm and INKAR.

Energy savings of 100 kWh/m<sup>2</sup>a – as indicated in our example above – result in energy cost savings of about 6.50 €/m<sup>2</sup>a. The multiplier shows that a price increase of 132 to 155 Euros per square meter living space is possible depending on the location. But this price premium only represents 48% to 56% of the total investment costs given above. Hence, investment costs between 122 and 145 Euros per square meter remain or, put differently, almost half of these costs are not reflected in higher housing values. A more detailed overview of energy savings depending on the chosen (single) renovation measure is given in Table 8.

These mean energy savings result from a field experiment on energetic renovation measures for residential buildings (co2online gemeinnützige GmbH, 2015). According to this study, houses with a mean energy consumption of about 156 kWh/m<sup>2</sup>a can achieve mean energy savings of 10% to 30% with single renovation measures. But the possible increase in housing values only covers up to 94% of the average investment costs, depending on location and on whether the investment costs are on the upper or lower end of the given range. Government funding for new technologies and energetic refurbishments, however, is not included here.

Table 8 Investment costs, energy savings and monetary benefits, depending on different renovation measures

Measure	mean energy savings in %	mean energy savings in kWh/m <sup>2</sup> a	avg. investment costs in €	monetary benefit in €	investment covered by surplus in %
heating boiler exchange	15	23.4	6,000 - 9,000	4,800 – 5,600	53 – 93
boiler exchange + solar	30	46.8	12,000 - 18,000	9,700 – 11,300	54 – 94
new windows	10	15.6	500 - 1,000 each	3,200 – 3,800	depends on # windows
roof insulation	11	17.2	5,000 - 20,000	3,500 – 4,100	18 – 82

Authors' illustration based on (Effizienzhaus-online; Energieheld; co2online gemeinnützige GmbH, 2015). Mean savings are related to buildings with an average energy consumption of about 156 kWh/m<sup>2</sup>a. The monetary benefit is calculated for a single-family house with living space of 156 m<sup>2</sup> based on mean energy savings in kWh using results given in Table 7. The range for the investment that is covered by the surplus in % is calculated by dividing the highest monetary benefit by the lowest avg. investment costs as well as the lowest benefit by the highest inv. costs.

Instead of comparing potential monetary benefits with investment costs, we now compare the increase in housing values to the value of the stated energy savings. For heating costs of 0.065 €/kWh, a single-family house with an average living space of 156 m<sup>2</sup> and a mean energy

consumption of 156 kWh/m<sup>2</sup>a will save energy costs of approximately 237 Euros per year when investing in a new heating boiler<sup>9</sup>. Depending on location, the monetary benefit is on average 22 times higher and thus exceeds these yearly generated energy cost savings by far. The exemplary net present value of energy costs saved amounts to 4,709 Euros for a useful life of 25 years and an interest rate of 1.86% (cf. (Deutsche Bundesbank)). Hence, about 91% of these energy cost savings are already reflected in the higher house price. This is another indication that the monetary value of energy efficiency improvements is rather adequately reflected in the housing prices – under the assumption of “myopic” expectations of homeowners, i.e. more or less constant energy prices in the future.

## 6 Conclusion

Increasing the energy efficiency of residential buildings is one key factor for lowering the CO<sub>2</sub> emissions in Germany to reach the goals defined in the Climate Action Plan 2050. Since the ownership rate in Germany accounts for at least 46.5%, private homeowners will play a major role when it comes to investments in refurbishments to improve the performance of a building. In order to identify benefits in terms of the property value for homeowners investing in such energy efficient retrofits, a repeated cross-sectional dataset for 2014 to 2018 is constructed, which includes more than 450,000 individual housing observations with full hedonic characteristics as well as different socio-demographic and socio-economic characteristics on a 1km<sup>2</sup>-grid level.

Using a hedonic pricing model in the common semi-logarithmic specification, we find evidence that energy efficient dwellings are sold with a price premium. Due to different market conditions, this surplus differs among regions. In large independent cities, a one-unit increase in energy efficiency results in a 0.045% increase in asking prices per square meter whereas a price premium of 0.111% can be generated in sparsely populated rural areas. Since property values are expected to decline in rural regions, homeowners could alleviate this development by increasing the energy efficiency of their dwellings.

Nonetheless, these monetary benefits only account for about 48% to 56% of the initial investment costs, in case of a complete refurbishment with improving the energetic performance of the respective building by 60%. Even single measures, such as the installation of a new sustainable heating system, are only reflected by up to 94% in the possible monetary surplus. However, government funding is not included here and might lead to a better coverage of needed investments. Furthermore, there might be some co-benefits of refurbishments, e.g. in terms of comfort or reliability. Comparing the net present value of future energy cost savings with the increase in housing values, however, shows rather consistent results: on average 91% of those savings are reflected in the monetary benefit – under “myopic” expectations regarding future energy prices.

Additionally, when exploring the impact of energy efficiency across time, our results suggest that environmental aspects have become increasingly important for housing prices over our sample period. The effects on asking prices were larger in 2018 compared to 2014 for all regional types. If this pro-environmental valuation holds on or even increases<sup>10</sup> in our society, we might expect the effect of energy efficiency on housing prices to increase further over the next years. This development, in combination with the new, less bureaucratic German Energy Act for Buildings and the federal funding for efficient buildings with its advantages in context of energetic refurbishments, therefore, may have the potential to increase the willingness to pay for energy efficient retrofits.

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<sup>9</sup> Savings in kWh/a = 156kWh/m<sup>2</sup>a \* 156m<sup>2</sup> \* 15% = 3,650 kWh/a \* 0.065 €/kWh = 237.25 €.

<sup>10</sup> E.g. due to help of the Fridays for Future movement.

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## Appendix

Table A1 Overview of all variables included in the regression

<i>lnPRICE</i>	Logarithmized price per square meter of living space, in Euro
<i>ENERGY</i>	Energy consumption for heating, measured in kWh/m <sup>2</sup> a
<i>HEATING</i>	Factor variable, indicating the heating system of dwelling <i>i</i> : <i>CHP</i> Combined heat and power <i>ELECTRIC</i> Electric heating <i>SCC</i> Self-contained central heating <i>DISTRICT</i> District heating <i>FLOOR</i> Floor heating <i>PELLET</i> Wood pellet heating <i>STORAGE</i> Night storage heating <i>STOVE</i> Heating by stove <i>OIL</i> Oil heating <i>SOLAR</i> Solar heating <i>PUMP</i> Thermal heat pump <i>CENTRAL</i> Central heating <i>GAS</i> Gas heating, reference category <i>unknown</i> No information about the heating system
<i>WATER</i>	Factor variable, indicating whether energy used for warm water consumption is included in <i>ENERGY</i> or not: 0 = is not included (reference category), 1 = is included, 2 = unknown
<i>lnLIVINGSPACE</i>	Logarithmized living space in square meter
<i>lnLOTSIZE</i>	Logarithmized lot size in square meter
<i>TYPE</i>	Factor variable, indicating the type of dwelling <i>i</i> : <i>DETACHED</i> Single-family house (detached) <i>SEMI-DET</i> Semi-detached house, reference category <i>TERRACED</i> Terraced house <i>MIDDLE</i> Terraced house, middle unit <i>END</i> Terraced house, end unit <i>BUNGALOW</i> Bungalow
<i>ROOMS</i>	Number of rooms
<i>FLOOR</i>	Factor variable, indicating the number of floors of dwelling <i>i</i> : 1 = max. 2 floors, 2 = between 3 and 4 floors (reference category), 3 = more than 4 floors, 4 = unknown
<i>CONSTRyear</i>	Factor variable, indicating the construction period of dwelling <i>i</i> : <i>before_1900</i> dwelling <i>i</i> was built before 1900 <i>btw_1900_1949</i> dwelling <i>i</i> was built betw 1900 and 1949 <i>btw_1950_1959</i> dwelling <i>i</i> was built betw 1950 and 1959 <i>btw_1960_1969</i> dwelling <i>i</i> was built betw 1960 and 1969 <i>btw_1970_1979</i> dwelling <i>i</i> was built betw 1970 and 1979; reference category <i>btw_1980_1989</i> dwelling <i>i</i> was built betw 1980 and 1989 <i>btw_1990_1999</i> dwelling <i>i</i> was built betw 1990 and 1999 <i>btw_2000_2009</i> dwelling <i>i</i> was built betw 2000 and 2009 <i>after_2009</i> dwelling <i>i</i> was built after 2009 <i>unknown</i> no information about the year of construction
<i>Mod2000</i>	Dummy variable, indicating whether dwelling <i>i</i> was modernized after 2000 or not: 0 = no (reference category), 1 = yes
<i>FACILITIES</i>	Factor variable, indicating the facilities of dwelling <i>i</i> : <i>SIMPLE</i> <i>NORMAL</i> Reference category <i>SOPHISTICATED</i> <i>DELUXE</i> <i>unknown</i> No information about facilities
<i>CONDITION</i>	Factor variable, indicating the condition of dwelling <i>i</i> : <i>1<sup>st</sup> OCC</i> 1 <sup>st</sup> occupancy after reconstruction <i>LIKE NEW</i> Like new <i>RECON</i> Reconstructed <i>MODERN</i> Modernized <i>RENOV</i> Completely renovated <i>WELL KEPT</i> Well kept, reference category <i>NEEDS REN.</i> Needs renovation <i>ARRANGEMENT</i> By arrangement <i>DILAPIDATED</i> Dilapidated <i>unknown</i> No information about condition
<i>CELLAR</i>	Factor variable, indicating whether dwelling <i>i</i> has a cellar: 0 = no (reference category), 1 = yes, 2 = unknown
<i>GUESTWC</i>	Factor variable, indicating whether dwelling <i>i</i> has a guest toilet: 0 = no (reference category), 1 = yes, 2 = unknown
<i>HITS</i>	Number of hits for the advertisement of dwelling <i>i</i>

Table A1 - continued

<i>lnPURCHPOWER</i>	Logarithmized purchasing power per capita, in Euro
<i>ADV_DURATION</i>	Duration of the advertisement of dwelling <i>i</i> , in months
<i>YEAR</i>	Factor variable, indicating when dwelling <i>i</i> was sold. Reference category = 2014
<i>POPULATION</i>	Population density: inhabitants per 1km <sup>2</sup>
<i>UER</i>	Unemployment rate, in %
<i>FOREIGN</i>	Share of households with foreign household head, in %
<i>CARS</i>	Number of cars per household
<i>NEIGHBORHOOD</i>	Factor variable, indicating the predominant building type in dwelling <i>i</i> 's grid cell: 0 = mixed development, 1 = 1-2 family homes in homogenous street section (reference category), 2 = 1-2 family homes in a non-homogenous street section, 3 = 3-5 family homes, 4 = 6-9 family homes, 5 = housing block: 10-19 households, 6 = housing block: more than 20 households, 7 = Industry/Trade
<i>DTYPE</i>	Factor variable, indicating the district type, where dwelling <i>i</i> is located: <div> <div><i>CITY</i></div> <div>large city</div> </div> <div> <div><i>URBAN</i></div> <div>urban area, reference category</div> </div> <div> <div><i>DENS</i></div> <div>rural area, densely populated</div> </div> <div> <div><i>SPARS</i></div> <div>rural area, sparsely populated</div> </div>
<i>EastWest</i>	Dummy variable, indicating whether dwelling <i>i</i> is located in East or West Germany: 0 = West Germany (reference category), 1 = East Germany
<i>market supply</i>	estimated as advertisements per inhabitant

Table A2 Type of heating and corresponding mean energy consumption

Type of heating	N		mean energy consumption in kWh/m <sup>2</sup> a
	total	in %	
<b>CHP</b>	486	0.11	113
<b>ELECTRIC</b>	4,209	0.92	171
<b>SCC</b>	6,045	1.33	179
<b>DISTRICT</b>	4,876	1.07	129
<b>FLOOR</b>	17,557	3.86	102
<b>GAS</b>	38,773	8.51	154
<b>PELLET</b>	1,170	0.26	142
<b>NIGHT STORAGE</b>	3,754	0.82	188
<b>STOVE</b>	12,487	2.74	231
<b>OIL</b>	21,809	4.79	193
<b>SOLAR</b>	301	0.07	90
<b>HEAT PUMP</b>	3,763	0.83	52
<b>CENTRAL</b>	283,179	62.18	171
<b>unknown</b>	57,004	15.52	178

Authors' calculation based on IS24.

Table A3 Energy consumption by construction period and modernization status

Construction period	modernized after 2000	N	mean energy consumption in kWh/m <sup>2</sup> a
<b><i>before 1900</i></b>	<i>no</i>	7,523	240
	<i>yes</i>	2,958	194 (- 46)
<b><i>betw. 1900 and 1949</i></b>	<i>no</i>	50,499	235
	<i>yes</i>	21,030	193 (- 42)
<b><i>betw. 1950 and 1959</i></b>	<i>no</i>	31,081	236
	<i>yes</i>	12,561	192 (- 44)
<b><i>betw. 1960 and 1969</i></b>	<i>no</i>	45,026	223
	<i>yes</i>	18,510	186 (- 37)
<b><i>betw. 1970 and 1979</i></b>	<i>no</i>	52,458	179
	<i>yes</i>	22,145	161 (- 18)
<b><i>betw. 1980 and 1989</i></b>	<i>no</i>	35,771	142
	<i>yes</i>	14,661	132 (- 10)
<b><i>betw. 1990 and 1999</i></b>	<i>no</i>	49,018	119
	<i>yes</i>	14,119	115 (- 4)
<b><i>betw. 2000 and 2009</i></b>	<i>no</i>	56,974	87
	<i>yes</i>	-	
<b><i>after 2009</i></b>	<i>no</i>	3,646	64
	<i>yes</i>	-	
<b><i>unknown</i></b>	<i>no</i>	13,137	176
	<i>yes</i>	4,287	161 (- 15)

Authors' calculation based on IS24.

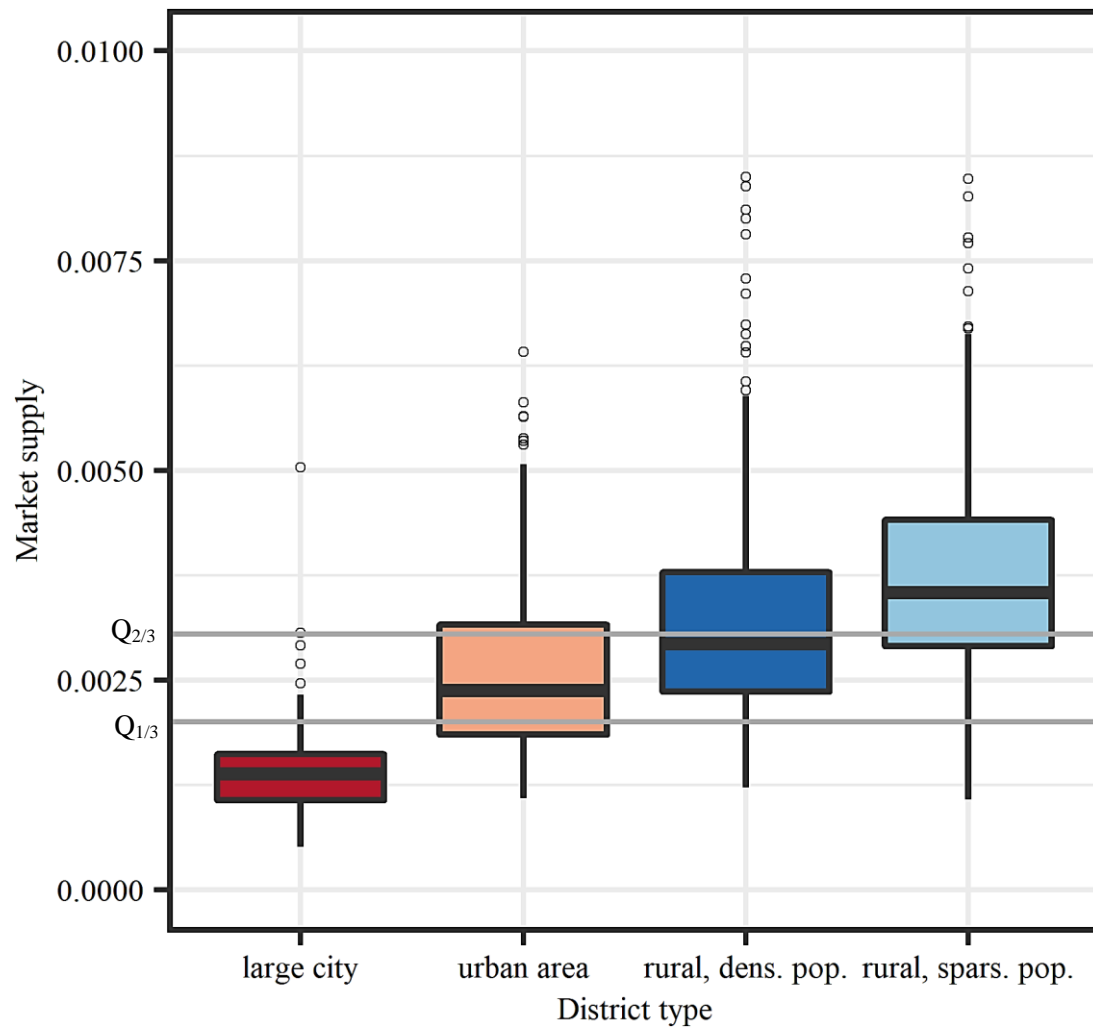


Figure A1 Distribution of market supply among regions  
 Authors' calculation and illustration based on IS24, microm and INKAR



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