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Split-incentives in energy efficiency investments? Evidence from rental housing[☆]

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ABSTRACT

Rental housing, where tenants are responsible for their own energy bills but landlords are responsible for the dwelling's energy performance, may pose a particular challenge for investments in energy efficiency. In this paper, we describe the severity of this split-incentive problem by comparing homes purchased for own use with those rented out on the German housing market, where the share of renters is particularly high and the majority of rented apartments is owned by private individuals. Using data on energy performance scores from Germany's largest online housing market platform between 2019 and 2021, we find on average economically small differences in the energy efficiency levels between apartments that differ by tenure type. Even though there are heterogeneous effects, also across broker types, by and large, our findings suggest that there may not be a critical energy efficiency deficit in the German multi apartment building sector.

1. Introduction

Heating and cooling of space make up the lion's share of energy needs in the residential sector in the EU and continue to be carbon-intensive energy services (European Commission, 2021). Consequently, climate policies heavily promote energy efficiency retrofits in the housing sector (Zhong et al., 2021), such as adding thermal insulation or upgrading heating systems, which can simultaneously reduce energy demand, household utility bills, and associated climate damages (Brounen et al., 2012).

A large number of studies has documented that on average there exists a "green premium" for investments in energy efficiency on the housing market (Aydin et al., 2020; Brounen and Kok, 2011; Fuerst et al., 2015; Fuerst and Warren-Myers, 2018) with significantly smaller effects in large cities, compared to other urban and in particular to rural properties (Taruttis and Weber, 2022). The literature has also established that the introduction of mandatory disclosure of energy performance certificates (EPC) plays a role in mitigating the information asymmetries that inhibit the full valuation of energy efficiency on the housing market (Frondel et al., 2019; Myers et al., 2022). Nevertheless, private investments in energy efficiency renovations of existing buildings may still fall short of the optimum (Allcott and Greenstone, 2012; Gerarden et al., 2017), resulting in the so-called energy efficiency gap (Jaffe and Stavins, 1994). Furthermore, both policy makers and scholars are increasingly concerned about a potentially high energy efficiency gap in rental housing (Krishnamurthy and Kriström, 2015; Myers et al., 2022).

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The separation of responsibilities between who pays for heating costs and who is responsible for energy efficiency renovations makes information asymmetries and incentive issues a specific challenge in the rental market compared to owner-occupied housing, highlighting the need to analyze rental housing in more detail (see e.g. Myers, 2020; Davis, 2023; Lambin et al., 2023). In Germany, with about 54%, more than half of homes are renter-occupied (Destatis, 2019), and tenants are responsible for their own energy bills in a large majority of rental contracts. This housing environment may be particularly problematic if it leads to significant under-investments in energy efficiency by landlords.[1]

In this paper, we describe whether rental properties indeed have lower energy performance standards compared to owner-occupied properties, which would indicate that landlords do not have appropriate incentives to invest in the energy efficiency of the apartments that they rent out on the housing market. Specifically, we empirically assess the magnitude of the differences in energy efficiency ratings between rental and owner-occupied homes.[2] To this end, we use comprehensive data on advertisements from ImmobilienScout24, the largest German online broker for apartments, spanning the period from 2019 to 2021, controlling for important determinants of energy efficiency such as location, age and size of the building, and time on the housing market as well as for broker types (see Breidenbach and Schaffner, 2020, for more information on the data set).[3] This allows us to evaluate whether the mode of tenure (owner versus renter) matters significantly on its own merit. Here we focus on the heating-related energy efficiency gap by using information on the energy efficiency level of buildings. In multi-apartment buildings, structural building-level characteristics, which account for the majority of an apartment's energy efficiency rating, are beyond the control of the tenants and are managed jointly by a group of apartment owners in the building.

There are multiple reasons for why we expect rental homes to have suboptimal levels of energy efficiency standards (see, for instance, Gillingham et al., 2012). One crucial reason is that tenants are often billed directly for their energy consumption, as is the case in Germany. Thus, tenants pay for their own utility bills, and consequently landlords do not reap the energy cost savings from energy efficiency investments.[4] Moreover, due to difficulties for tenants to observe the true energy cost of homes they move to as well as the true energy efficiency level of homes they reside in, landlords may not be able to recover costs from energy efficiency investments through higher rents, leading to under-investments by landlords (Myers, 2020; Lang and Lanz, 2021). In Germany, this split-incentive problem (see also Krishnamurthy and Kriström, 2015) may even be aggravated by the fact that the vast majority of low-income households (who mostly rent) reside in multi-apartment buildings, that may be further subject to binding rent control (Breidenbach et al., 2022). Hence, there might be a trade-off between rent control and the landlord's incentives to invest in energy retrofits. Overall, it may thus be reasonable to predict a long-term energy efficiency problem in the rental market.

Our results suggest that on average there is only a small divergence (up to 6 percent) in the energy quality of properties by the mode of tenure in the market of apartments. This is in line with the study by Petrov and Ryan (2021) for the Irish rental sector. However, we detect considerable heterogeneous effects. First, the gap appears to be systematically larger when real estate agents are involved compared to transactions through private individuals. However, this may be an artefact of the differences in EPC disclosure rates between different broker types, which we also explore in the analysis. Moreover, new apartments inhabited by owner-occupiers are on average more energy-efficient than new apartments for rental use. To be precise, the difference amounts to roughly 5 percent for transactions among private individuals but up to 10 percent when real estate agents rent out new apartments. A reason could be that the top energy efficiency standards (A+ or A) tend to be priced at a significantly higher premium on the sales market, which may make them economically more suitable for self-use, rather than for rental income. In addition, we detect that the divergence in energy efficiency levels is larger in urban and less wealthy areas compared to rural and wealthier areas. Yet, even though the gap widens, the economic effect is still moderate as differences amount to maximum 5 percent in most cases. Given an average apartment size (75 m^2), EPC score (110 kWh/m^2) and historical average natural gas prices[5] (EUR .06/kWh), the additional burden paid by tenants amounts to a maximum of roughly EUR 25 per year.

We offer four reasons for the small overall differences in the energy requirements. First, existing multi-family buildings might not be sorted by housing tenure. That is, there is a mix of both renter-occupied and owner-occupied apartments available in existing buildings, which is reflected on the housing market. Since investment decisions are made jointly by groups of apartment owners in multi-unit buildings and owner-occupied apartments tend to be larger, more weight is likely to be given to the investment vote of owner-occupiers over landlords of rental apartments in the same building. As our analyses uses building-level energy efficiency values, differences between apartments within the same building cannot be observed. If differences in tenancy status would be correlated with apartment-level energy efficiency investments, we would possibly only be capturing parts of the energy efficiency gap. However, since we focus on heating-related energy efficiency, respective investments in Germany in multi-apartment buildings,

[1] To distribute the incentives to invest in energy efficiency, in 2021 the German federal government, for instance, brought into force a carbon price for the consumption of heating fuels. The cost increase is split between both parties in private rental contracts: the landlord that owns the property and the renter living in it (Flachsland and Levi, 2021).

[2] The extent of the split-incentive problem depends on how it is measured. However, all measurement issues apply to both owner-occupied and tenant-occupied properties in our analysis.

[3] Throughout the paper, "broker type" refers to either private individuals (offering homes for sale or rent directly on the market) or real estate agents.

[4] Note that 60 percent of apartment units are owned by private individuals in Germany (see Tables A.1 and A.2). Statistics on the ownership structure at the building level are not available, however. The share of buildings that are fully owner-occupied is an unknown statistic, for example. Nevertheless, even for buildings completely housed by owner-occupiers, there may still be a collective action problem among apartment owners — leading to below-optimal investments in energy efficiency compared to when the entire building is owned by one large owner, e.g. a private company or public institution.

[5] We consider the historical average gas price, from 2013 to 2019 in Germany, reflecting a good approximate measure of energy costs relevant for long-term energy efficiency and heating type decisions that took place before the property was posted on the online housing market. Source: https://www.verivox.de/gas/gaspreisentwicklung/

like replacing the windows or the central heating system, can only be decided on jointly by apartment owners, such a difference between owner-occupied and rented apartments within the same building is unlikely. Second, the burden of renovation costs is shared by multiple apartment owners in a building, which may allow sufficient financial buffer and thus economic incentives to invest in the energy efficiency of existing multi-apartment buildings. Moreover, there might not be any differences in investment preferences between landlords and owner-occupiers as suggested by Fanghella et al. (2023) for the French housing market. Last, such low differences may also be a result of a general low willingness to renovate buildings to higher standards among homeowners in Germany.

By comparing the energy efficiency performance of rental homes to owner-occupied homes, we contribute to two strands in the literature. First, this paper relates to the broad literature analyzing the split-incentives dilemma in the rental market (e.g. Cellini, 2021; Gillingham et al., 2012; Melvin, 2018). For instance, using cross-sectional survey data from 11 OECD countries, Krishnamurthy and Kriström (2015) detect that owners are substantially more likely to have access to energy-efficient appliances and to better insulation. In a similar vein, Davis (2019, 2023) finds empirical evidence for a homeowner-renter gap for electric appliances and electric vehicle ownership, showing that renters are more likely to have electric heating appliances, electric dryers and electric stoves, but are less likely to own an electric vehicle. The author argues that this gap results from the split-incentives dilemma between landlords and tenants with landlords preferring electric appliances as they are less capital-intensive and landlords not investing in charging infrastructure due to difficulties to convey important information to tenants to recover the investment costs through higher rents. Charlier (2015) shows for French households that tenants have higher energy expenditures than homeowners due to energy-inefficient building characteristics. We add to the literature by using objective energy efficiency ratings (determined by structural building characteristics that strongly influence a household's heating consumption) in our analysis, instead of considering smaller electrical appliances or stated survey information as in previous studies.

Furthermore, there is a rich array of studies in different contexts that offer policy solutions to mitigate the split-incentive problem in the residential sector (e.g. Ástmarsson et al., 2013; Carroll et al., 2016; Lambin et al., 2023). For instance, Charlier (2015) illustrates that tax credits are ineffective in the split-incentives context, recommending mandatory measures, such as minimum standards. Weber and Wolff (2018) compare theoretical heating energy consumption prior to and after a retrofit with actual consumption data. They show that despite a reduction in energy consumption of 70%, more than half of the households experience a cost increase owed to higher rents after retrofit, emphasizing the importance of alternative financing models.

Second, we add to the literature analyzing the size of the energy efficiency gap in the rental market. Only few studies have estimated the economic significance of the energy efficiency problem in rental housing (Broberg and Egüez, 2018; Nie et al., 2020; Myers, 2020; Petrov and Ryan, 2021). For instance, Broberg and Egüez (2018) focus on multi-dwelling buildings and find that ownership matters for the energy performance of these buildings with privately owned buildings having a better energy performance than publicly owned ones. Petrov and Ryan (2021) find a larger difference between rental and non-rental properties' energy efficiency in markets with scarcity in rental property supply. Using a causal framework on asymmetric information between landlords and tenants, Myers (2020) estimates that energy use could be 1%–3% lower if asymmetric information was corrected for. We provide further empirical evidence on the size of the energy efficiency gap in the rental market by answering the following question: what is the extent to which renter-occupied homes underperform in terms of energy efficiency compared to owner-occupied homes, ceteris paribus? Germany presents itself as an interesting case study with by far one of the largest rental apartment markets in Europe. Almost half of the population rents their residence, and the majority of renters live in multi-apartment buildings (Breidenbach et al., 2022). Thus, this paper is the first to analyze data from a rental market that serves a significant share of the population and covers all geographic regions in Germany.

In the subsequent section, we present a brief overview of the German housing market. Section 3 describes the data set and presents summary statistics. In Section 4, we provide a brief assessment of selective disclosure of energy performance certificates, followed by the main descriptive analysis in Section 5. The last section summarizes and concludes.

2. Background

Germany aims to achieve carbon neutrality by 2045 whereby an important milestone is the reduction of carbon emissions by 65% by 2030 compared to 1990. One crucial sector to reach these targets is the building sector, since it accounts for roughly 15% of Germany's carbon emissions (UBA, 2022). To reduce emissions from buildings, a great deal of homes need to be retrofitted. However, the rate of renovation in Germany's residential building sector has been as low as 1% in the past (Cischinsky and Diefenbach, 2018) and has not increased despite generous governmental subsidy programs for energy-efficient retrofits (Frondel et al., 2022).

There are a number of instruments that aim to foster residential energy efficiency. For starters, Germany introduced a carbon pricing scheme at the outset of 2021 that raises the price of fossil fuels (see Flachsland and Levi, 2021, for more information). By increasing the cost for gas and heating oil, the two most common heating fuels in German buildings (Destatis, 2019), carbon pricing aims to induce households to invest in energy-efficient solutions. To facilitate energy conservation in the building sector, especially in existing buildings, the new Building Energy Act (GEG) bundles the energy requirements for new and existing buildings (The Federal Government, 2020). The GEG replaces previous regulations that established building codes for energy efficiency, such as the Energy Conservation Ordinance (for an overview of the most important years of amendments in the energy conservation ordinances, see Table A.3). The Energy Conservation Ordinance (Energieeinsparverodnung, EnEV) of 2002 is considered to be a milestone for the energy efficiency in buildings. It dictates an energy requirement of less than 100 kWh/m^2 for new buildings compared to 150 kWh/m^2 from the previous regulation.

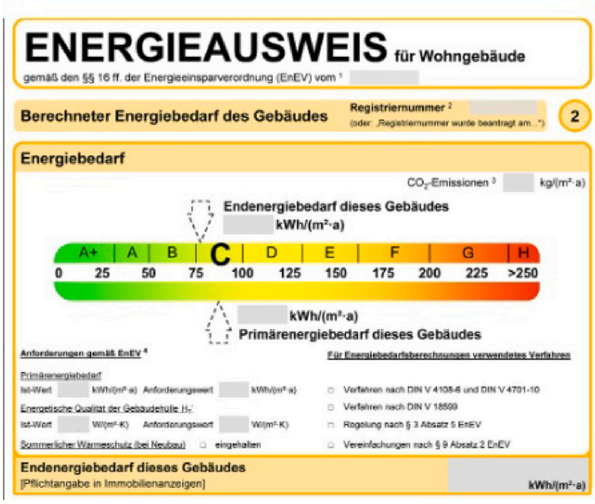


Fig. 1. Energy performance certificate.

In addition, a number of other support measures and bans in the building sector accompany the carbon price. First, the Federal government decided to prohibit the installation of heating systems using heating oil as of 2026. Second, various subsidy programs exist to further support retrofit measures: Replacing an old oil heating system with an energy-efficient heating system is supported with a federal subsidy of up to 45% of the purchase price. Buying, building or renovating buildings according to energy efficiency standards of varying stringency are financially supported by the Federal Development Bank (KfW) with low interest loans and repayment bonuses of up to 40% (Sebi et al., 2019; The Federal Government, 2022).

Individual energy efficiency measures are subsidized by the KfW and cover up to 20% of the cost. Finally, for energy-related retrofits, such as the insulation of roofs and walls, the renewal of windows or the installation of energy-efficient heating systems, tax credits of up to 20% (maximum EUR 40,000) of the cost can be claimed (The Federal Government, 2022). Yet, these tax incentives can only be exploited by owner-occupiers. More generally, the benefits of such programs might be different for tenants compared to homeowners because of the split-incentives dilemma (Gillingham et al., 2012): for homeowners, incentives are aligned, i.e., they make an energy-efficient investment and reap the benefits of lower consumption rates and thus lower energy bills. In contrast, on the rental market the incentives diverge, as tenants usually benefit from better energy efficiency because they pay the energy bills, but landlords bear the cost of investment. However, tenants may be less informed than homeowners and landlords about the thermal quality of their dwelling.

To mitigate this information asymmetry, many governments have introduced energy performance certificates with mixed effects on purchase prices and rents (e.g. Eichholtz et al., 2013; Hyland et al., 2013). The German government introduced mandatory EPCs in May of 2014 (Frondel et al., 2019). Specifically, vendors and landlords are obliged to disclose energy-related information whenever their dwelling is on sale or up for rent, that is, also in real estate advertisements.[6] The EPCs entail information on the building's annual energy consumption in kilowatthours (kWh) per square meter and the related CO_2 emissions (Fig. 1).[7] An important feature of the EPC is that it is determined at the building level, not the apartment level. It is fitting that even in multi-unit apartment buildings with multiple landlords, decisions about energy efficiency measures are made collectively at the owners' meeting and are thus building-level decisions. The German Condominium Act ("Wohnungseigentumsgesetz") provides the basic legal framework for the community of owners to discuss anything related to the common property, which includes the common areas such as the stairwell, the facade or the roof, and thus decisions about their insulation. Therefore, even though the owners depend on each other to make decisions about energy retrofits, they are the ones responsible for these issues. The main determinants to calculate the specific energy consumption are the building's construction year, the number of apartments, floor size, the heating source, and the kind of insulation. Moreover, the EPC splits the distribution of energy performance into discrete energy efficiency classes, ranging

[6] Certain buildings are exempt from the disclosure requirement: These are for instance buildings that are not heated or cooled with the help of energy, residential buildings that are used for a maximum of four months per year (fixed period of use), such as holiday or weekend homes, and residential buildings that are used for a limited period per year and whose energy consumption during this period is less than 25% of the expected energy consumption if the building is used all year round. Other exemptions apply to monuments and small buildings with a floor space of up to 50 square meters as well as a series of operational buildings that require low temperatures (The Federal Government, 2020).

[7] There are two types of energy certificates: the demand certificate (§81 GEG) and the consumption certificate (§82 GEG). In the case of the demand certificate, the energy requirement is calculated on the basis of the building and heating characteristics and a standardized consumption behavior. In the case of the consumption certificate, the energy demand is determined on the basis of measured consumption and building characteristics. For new as well as old buildings that do not comply with the First Heat Insulation Ordinance of 1977 (see Table A.3) and have less than five residential units, the demand certificate is obligatory (§80 3 GEG). For all other residential buildings, both energy certificates are equally valid and can be freely selected by homeowners. Yet, data access for the consumption certificate is usually easier, such that the consumption certificate is often cheaper to obtain.

from A+ to H, with A+ indicating the most energy-efficient buildings. Each step on this discrete scale amounts to a difference of 25 kWh/m^2.

Our focus on Germany is particularly suited to explore the problem of split incentives between tenants and landlords because Germany has one of the lowest homeownership rates among the OECD countries (Andrews and Sánchez, 2011). With roughly 50%, Germany has the second lowest homeownership rate in Europe after Switzerland, while the EU average amounts to about 70% (Eurostat, 2022). In addition to specific housing policies like high transfer taxes when buying real-estate and no tax deductions for mortgage interest payments that tend to discourage homeownership in Germany (Kaas et al., 2020), it is likely that social norms and preferences also play a significant role to nudge German households away from pursuing homeownership (Huber and Schmidt, 2022). In other words, for some households the decision not to own a home may not be due to a lack of investment opportunities, but rather a lifestyle choice supported by a sufficiently high-quality rental housing supply.

Moreover, in Germany private individuals are heavily engaged in renting out living space in multi-apartment buildings.[8] About 60% of dwellings are rented out by private landlords and the remainder by large public or private real estate companies (Destatis, 2019). However, the two segments of owning and renting apartments are not completely separated. Owners of apartments in Germany have the possibility to stop the rental contract with the tenant if they want to use the apartment for themselves or for a close family member ("Eigennutzung" or self-use). Yet, to prevent arbitrary terminations by the landlord, tenant protection regulates all requirements for registering personal use. For instance, a certain period of notice must be granted to give tenants time to find a suitable replacement or to even lodge an objection. If all requirements are adhered to and landlords give a clear reason for their desire to use the apartment themselves, private landlords can start living in the apartment that they previously rented out. In this case, landlords may have stronger incentives to invest in energy-efficiency, as they can later reap the benefits of lower energy bills themselves.

3. Data

For the empirical analysis, we use data on apartments that were offered for purchase or rent on the largest online housing market in Germany between January 2019 to December 2021 (see RWI and ImmobilienScout24, 2020, for more information on the data set). We are limited to using data from 2019 onward because the required information on the broker type is not available before 2019 in the dataset. To assess the split-incentive problem in energy efficiency investments, we use the subsample of apartment offers that were privately owned. We do not consider properties owned by companies or public institutions because we expect investment incentives to be different compared to individuals who own property. Moreover, such actors are usually not engaged in selling apartments online, which impedes a proper comparison of apartments within broker types. Thus, we limit the data to those properties that were offered directly on the market by private individuals or indirectly through real estate agents.[9]

In addition to the energy performance score of the building, other building-level information available are the construction year and the number of floors in the building. The size of the entire building measured by the number of apartments is not available, but we approximate this variable with the number of floors in the building. For our analysis, we differentiate between the following privately owned real estate listings on the housing market: (1) owner-occupied apartments for sale (looking for new owner), (2) renter-occupied apartments for sale (looking for new owner/landlord), and (3) apartments for rent (looking for new tenants). Thereby, we are able to identify those apartments that were purchased as an investment for rental income and distinguish them from those apartments purchased for self-usage.[10]

To prepare the data for our analysis we consider that many brokers/sellers strategically remove the original apartment offer and repost it on the housing market website, sometimes multiple times within a few months, supposedly to increase the number of customer views. In such cases, to avoid double or multiple counting of the same apartment offer on the market, we drop all past instances of the apartment offered within the three year period (2019–2021) and keep only the latest offer on the market before the apartment eventually vanished from the online platform.[11] This results in a total of 719,948 observations. With 74%, the major share of advertisements was posted for renting (Table 1). Among the apartments offered for sale, we note that 75% were owner-occupied and roughly 25% were renter-occupied.

Table 1 presents descriptive statistics of our sample from the housing market by offer type of the apartments. We observe that owner-occupied apartments for sale do not differ significantly from properties on the rental market in terms of observable characteristics, including the construction year and the building standards (Columns 1 and 3). This likely explains why the variable of key interest, the energy performance scores in the first row of Table 1 are close in magnitude. In contrast, compared to owner-occupied properties, renter-occupied apartments for sale that offer rental income to home buyers have a lower asking price, are more likely to be located in West Germany and are on average older, offer smaller living space, and are considerably less often sold for the first time after construction or substantial renovation (First Occupancy).

[8] We observe that on the sale market for detached and semi-detached houses, on Germany's largest online housing market from 2014 to 2021, only 1.5% of the houses sold were renter-occupied. Thus, almost all houses are sold to owner-occupiers and the rental market is rather the market for apartments and not houses.

[9] Table A.4 in the Appendix shows that the EPC score and construction year of rental apartments offered by the housing industry (which is only active on the rental market) are comparable to those of private individuals and real estate agents.

[10] Note that properties that are not renter-occupied during sale and thus sold vacant to potential owner-occupiers are listed on the housing market for significantly higher asking prices on average (see Table 1).

[11] The results are virtually the same if we keep the first observation for each apartment instead.

Table 1
Differences in properties by apartment offer type.

	Apartments for sale		
	Owner-occupied	Renter-occupied	Rental market
EPC score (kWh/m^{2}a)	110	119	111
	(50)	(42)	(52)
Listing Price in EUR	387,616	247,465	–
	(404,871)	(201,599)	–
Construction Year	1970	1962	1969
	(36)	(37)	(40)
Number of Floors	4.0	4.1	3.6
	(2.7)	(2.4)	(2.0)
Living Space (m^2)	87	72	72
	(45)	(38)	(30)
Relative Frequencies			
Built 2002+	0.18	0.05	0.21
EPC Type	0.36	0.23	0.38
Warm Water	0.61	0.65	0.61
East	0.29	0.45	0.33
Observations			
N	141,897	48,233	529,818
Share	20%	7%	74%
Seller Type			
Private Offer	10%	12%	47%
Real-Estate Agent	90%	88%	53%
First Occupancy			
Not First	77%	98%	83%
First Occupancy	23%	2%	17%

Notes: The table describes the main variables used from the data on housing transactions that took place from 2019 to 2021 on RWI and ImmobilienScout24 (2020). The first row for each variable reports the mean, and standards deviations are reported in parentheses. Higher EPC score indicates a lower level of energy efficiency. Number of Floors is a characteristic of the apartment's building, while Living Space reports the square meter space available in the apartment offered. EPC Type equals 1 if it is a Energy Demand Certificate, 0 for a Consumption-Based Certificate. Warm Water is a dummy variable indicating whether the EPC score is inclusive of water heating. East equals 1 for properties in Berlin, Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, and Thuringia, otherwise 0. First Occupancy indicates whether the apartment on offer was listed as “First Occupancy" or “First Occupancy after Reconstruction".

Next, we explore the distributions underlying the mean statistics in the EPC score. Note that higher EPC scores denote that the building has higher energy requirements (kWh) per square meter of living space per annum and thus a lower level of energy efficiency. Fig. 2 plots the distributions of energy performance scores for all three apartment offer types. Plot A suggests a much higher frequency of owner-occupied apartments with high energy efficiency standards (EPC closer to zero) compared to apartments on the rental market.

In Panel B we omit those apartments that were either listed as “first occupancy” or “first occupancy after reconstruction” and further observe that the distributions become more similar to each other. We can infer that buildings with new or fully renovated apartments are significantly more energy-efficient than existing buildings and also more likely to be owner-occupied. It is further noteworthy that we observe comparable shares of apartments with poor energy performance standards (e.g. scores above 200 kWh/m^{2}a). Hence, even though first occupancy owner-occupied apartments for sale appear more often in the top energy efficiency class, rental properties are not more likely to appear at the bottom of the distribution.

In the appendix, we check these differences over time as well. Fig. A.1 shows that the differences in average energy performance are statistically indistinguishable across modes of tenure once we remove first-occupancy apartments. In Fig. A.2 we further describe the distribution of energy efficiency classes, grouped by the stringency of building standards (that apply by the year of construction). In a housing market with a major problem of split-incentives in energy efficiency investments between owner-occupiers and landlords, we would expect to see a right-skewed distribution of energy efficiency (higher concentration of apartment buildings towards higher efficiency classes) for owner-occupied homes and a left-skewed distribution of energy efficiency for rented homes. Yet, we fail to detect such a large gap in Fig. A.2. As demand and consumption certificates rely on different calculation methods, with the consumption certificate being more influenced by the residents' heating behavior, there may be systematic differences in the energy performance scores depending on the type of certificate. We show how energy performance scores differ between apartment offer types depending on the type of energy performance certificate in Appendix Table A.5. Whereas differences in the energy performance scores between all three offer types are rather small across both types of certificates and amount at a maximum to 11 kWh/m^{2}a, we see that the patterns depend on the type of certificate. For instance, the energy demand certificate reports on average slightly higher energy performance scores for apartments for rent for buildings built between 1984 and 2001 compared to buildings of the same category that are renter-occupied or owner-occupied for sale, while the average energy performance scores

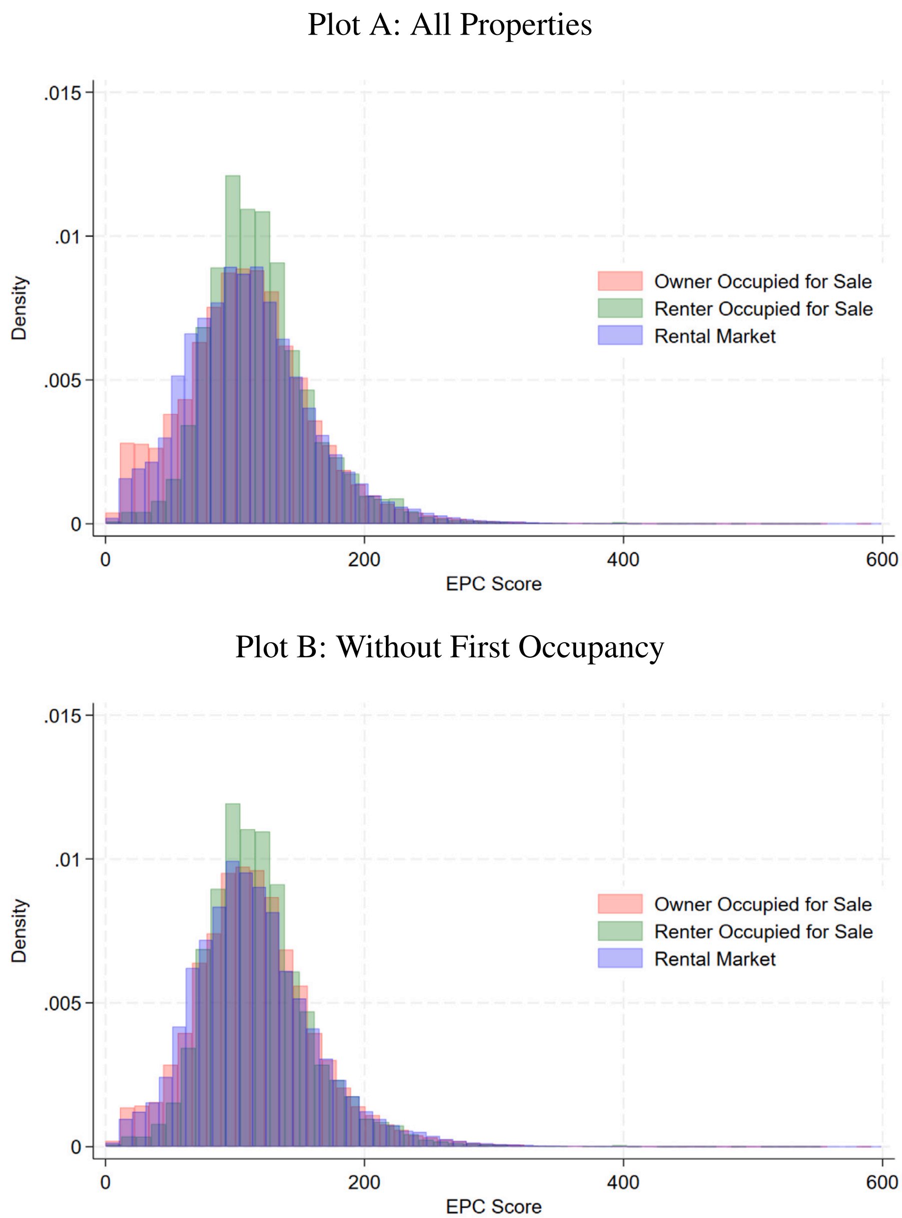


Fig. 2. Distribution of EPC scores in the market for apartments.
Notes: The graphs illustrate the distribution of energy performance certificate (EPC) scores by whether the apartment is owner-occupied for sale, renter-occupied for sale or for rent. Plot A plots the histogram for all properties observed from 2019 to 2021, while in Plot B, the sample was limited to those apartments that were not identified as "First Occupancy" or "First Occupancy after Reconstruction". By doing so we remove new properties from the sample. Thus, Plot B is a closer representation of existing apartments that went off the housing market during the three year window.

are lower or the same for apartments for rent when comparing them to owner-occupied or renter-occupied apartments for sale based on the energy use certificate. We control for the EPC type in our analysis below.

As mentioned in the previous section, EPCs are issued at the building level, rather than at the apartment level. Energy performance scores that reflect the energy efficiency attributes of the building are well suited for our analysis, because the thermal comfort of an apartment depends largely on the condition of building-level features. For instance, the facade (outer wall) and the roof are critical factors affecting the insulation performance of all living units in a building. Nevertheless, we also observe the condition of the apartment in our data. Fig. 3 illustrates the distribution of apartments sold by the mode of tenure. The graph shows that renter-occupied for sale and rental market apartments are not more likely than owner-occupied apartments for sale to fall in the "Needs Renovation" or worse category.

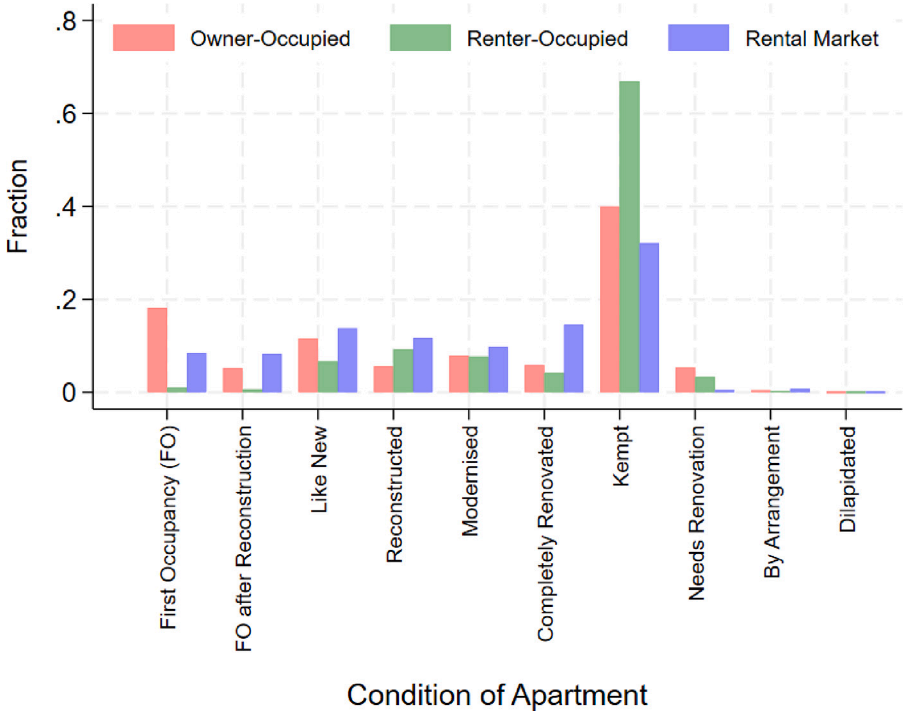


Fig. 3. Condition of apartment by tenure status.
Notes: The graph plots the share of tenure type (owner-occupied, renter-occupied for sale versus rentals) by the reported condition of the apartments that left the housing market from 2019 to 2021. Note that the information on the condition of the apartment was not available for approximately 34 percent in the apartment sale data set and about 32 percent for the rental apartment data set.

Table 2
EPC compliance by apartment offer type.

	Compliance rate	N
Owner-Occupied		
Private offer	0.4	31,745
Real-estate agent	0.68	178,530
Renter-Occupied		
Private offer	0.4	9191
Real-estate agent	0.74	55,590
Rental Market		
Private offer	0.33	502,912
Real-estate agent	0.75	492,184
Total	0.56	1,270,152

4. Addressing self-selection in EPC disclosure

While the dependent variable in our main analysis is the EPC score, we do not observe it for all apartments that were up for sale or rent on the market in the sample because of selective reporting. In May 2014, it became mandatory in Germany to disclose information on energy performance certificates (EPC) for properties that were up for sale or rent on the housing market. The majority of EPC scores observed on the housing platform did indeed become available only after this date. But despite the legal obligation to disclose energy-related information, there remained a high share of non-disclosing brokers/sellers in the market for apartments and houses, suggesting that some brokers or sellers with bad lemons may have had the incentive to not disclose energy-related information (for a related discussion, see Frondel et al., 2019). Table 2 demonstrates that in fact there are stark differences in the compliance rate by broker type in particular. As we only consider privately-owned apartments, we distinguish between *indirect offers*, where the apartment is offered through a broker like a real estate agent, and *direct offers*, where the property is posted directly by the private landlord on the online housing market. The compliance rate is significantly higher when individuals arrange their apartments through a real estate agent compared posting the property directly on the online housing market. Furthermore, the share of apartment posts by owners that disclose the EPC on the rental market was only 33% in the period from 2019 to 2021.

Table 3
Determinants of EPC availability.

	$y = \mathbb{1}(EPC\ available)$		
	(1)	(2)	(3)
Broker Type (Base: Private)			
Real-estate agent	0.396***	0.281***	0.285***
	(0.001)	(0.003)	(0.003)
Offer Type (Base: Owner-Occupied)			
Renter-Occupied	0.058***	0.003	−0.004
	(0.002)	(0.005)	(0.005)
Rental Market	0.046***	−0.059***	−0.048***
	(0.001)	(0.003)	(0.003)
Broker Type × Offer Type (Base: Private × Owner-Occupied)			
Real-estate agent × Renter-Occupied		0.065***	0.064***
		(0.006)	(0.006)
Real-estate agent × Rental Market		0.132***	0.125***
		(0.003)	(0.003)
Year of Construction (Base: Pre 1978)			
1978–1983			0.047***
			(0.002)
1984–1994			0.089***
			(0.001)
1995–2001			0.105***
			(0.001)
2002+			0.014***
			(0.001)
Number of Floors in Building (Base: 0–1 Floors)			
2 Floors			0.040***
			(0.002)
3 Floors			0.059***
			(0.002)
4 Floors			0.057***
			(0.002)
5 Floors			0.088***
			(0.002)
6+ Floors			0.101***
			(0.002)
Observations	1,278,820	1,278,820	1,278,820
R^2	0.200	0.201	0.209

Notes: The table presents estimated versions of Eq. (1). The binary dependent variable indicates whether the EPC issued for the building was available in the real estate apartment advertisement. The coefficient estimates on the year of posting and the month of posting were omitted for readability purposes. All specifications included zip code fixed effects. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In the following, we analyze this question of different compliance rates more in detail. We cannot control for this selection bias but an exploration of the determinants of EPC disclosure can inform our understanding of whether the EE differences we find between rental versus owner-occupied are under-estimates or not. We assess the determinants of EPC disclosure on the housing market for apartments using the following equation:

$$EPC_i = \alpha + \beta \text{Broker Type}_i + \delta \text{Offer Type}_i + \gamma \text{Broker Type}_i \cdot \text{Offer Type}_i + \mathbf{z}_i' \boldsymbol{\pi} + \phi_t + \kappa_m + \mu_z + \epsilon_i, \quad (1)$$

where EPC_i is equal to one if the energy performance score was reported for apartment offer i. $Broker\ Type$ distinguishes between direct offers (directly posted by the private landlord) and indirect offers (via a real estate agent). $Offer\ Type$ captures the tenure type, that is, whether the apartment is for purchase (owner-occupied or renter-occupied for sale) or offered on the rental market. To allow for any offer-type-specific disclosure differences between brokers, we further include the interaction term. Vector **z** covers building characteristics (year of construction grouped by applicable building energy regulation, number of floors of building) and location (spatial planning region type). Finally, we capture year and month of posting effects using ϕ_t and κ_m respectively, and zip code fixed effects using μ_z.

Table 3 presents the results of a linear probability model estimation of Eq. (1). Column 1 suggests that private individuals have lower probabilities of EPC disclosure compared to real estate agents and EPCs for owner-occupied apartments are disclosed less often compared to both types of rental apartment offers (sale and rent). We further estimate two models without and with the inclusion of the covariate vector **z** in Columns 2 and 3, respectively. The estimates of the coefficients confirm the pattern observed in Table 2. Real estate agents are significantly more likely to disclose EPC information than private individuals in the market for rental apartments as shown by the interactions of broker type and offer type in the third row block, which suggests that disclosure rates are higher by 6 and 13 percentage points for renter-occupied and rental market apartments, respectively. Moreover, we showed previously in Table 1 that on the market for apartments on sale, the vast majority (approximately 90%) of apartments are sold by real estate agents, and this is also the case for renter-occupied apartments. For these reasons, we expect the problem of self-selection into providing EPC scores to be less severe when comparing between owner-occupied and renter-occupied apartments for sale in general. More importantly, when comparing owner-occupied apartments and rental market apartments in the main analysis that follows, we expect to overestimate the energy-efficiency differences among offers made by real estate agents (see Appendix Table A.6).

In contrast, half of the apartments on the rental market are offered by private individuals, for whom we observe a lower compliance rate in the rental market (coefficients of −0.59 and −0.48 in Columns 2 and 3 respectively). This likely implies a much higher tendency for selective disclosure among offers made by private individuals. In the main analysis that follows, we would then underestimate the energy-efficiency differences among offers made by private individuals.

Generally, the estimates suggest that apartments in newer and larger buildings make their energy performance certificates available on the online platform at higher rates. Surprisingly, apartments in the newest year of construction bracket (2002+) do not have a substantially higher compliance rate than properties located in apartment buildings that were built before 1978, when building regulation began (statistically significant coefficient of 0.014). This may be because prospective buyers or renters already have a strong signal of building quality from the fact that the property is newly constructed. Finally, the estimates also suggest that EPC disclosure rates do not vary considerably between region types (urban, semi-urban, and rural). Overall, differences of EPC disclosure rates by regions and building type are dominated by differences across broker types and whether the property was for sale or rent.

5. Empirical results

In this section, we explain the empirical strategy and results. The next Section 5.1 describes the equation we use to descriptively estimate the split-incentive problem among private owners of apartments. We describe the main results in Section 5.2 before conducting a heterogeneity analysis in Section 5.3.

5.1. Estimation

Thus far, we have considered merely the average performance of buildings without accounting for building-specific factors that directly affect the energy efficiency standards of properties, such as the construction year and building size. The time when the property appears on the housing market for sale or rent may also be linked to varying energy efficiency levels. In the previous section, we investigate the main predictors of compliance with the EPC disclosure mandate in Germany and show that selection across apartment offer types depends heavily on the type of broker on the housing market. Specifically, the propensity to disclose EPC information differs significantly between private offers and those through real estate agents, which may bias our estimates for energy efficiency differences between owner-occupied properties for sale and those that are rented out (renter-occupied for sale and rental market). In the analysis below, we take into consideration the discrepancies in disclosure probabilities when interpreting the differences in energy efficiency. To account for these influencing factors, we estimate the energy efficiency of apartments separately for each broker type (private and real estate agent) using the following linear regression specification:

$$y_{imt} = \alpha + \beta \text{Offer Type}_i + \kappa_m + \phi_t + \mu_z + \mathbf{x}_i' \boldsymbol{\pi} + \epsilon_{it}, \tag{2}$$

where y_{imt} denotes the log of the EPC score (measured in kWh/m^{2}a) of the building, in which apartment i was sold in month m and year t. Our key explanatory factor, $Offer\ Type_i$, is a categorical variable for the type of property on offer. It equals 1 if the apartment was owner-occupied for sale , which is our base category, 2 if an apartment was renter-occupied for sale , and 3 if the apartment was offered for rent on the market (Rental Market). As we denote EPC in logs, the corresponding parameter β can be interpreted as a semi-elasticity.

Moreover, we control for building-level covariates to capture the stringency of building codes that apply to properties, determined by the year of construction. Newer buildings are more energy-efficient by law and thus do not require significant investment by the owner after construction. Controlling for construction year allows us to compare the performance of buildings that were subject to the same energy standards during construction, but were used for rental purposes versus occupied by the owner. Similarly, the size of the building is an important determinant of the energy efficiency standard. Finally, we include fixed effects for the type of energy certificate (demand versus consumption) in order to control for methodological differences in calculating energy requirements of the building. We capture these characteristics of the building associated with the apartment on offer in vector $\mathbf{x}_i$. Last, we employ a rich set of time and location-based fixed effects. Specifically, κ_m and ϕ_t denote month and year fixed effects for when the apartment was posted on the housing market, and μ_z are zip code fixed effects.

This estimation procedure allows us to account for differences in EPC disclosure rates across private versus real estate agents. Specifically, it enables us to compare the energy performance of similar apartments (after controlling for location, building year, size, etc.) within the same type of broker. Since the disclosure rates differ across broker type significantly (real estate agents tend to provide the EPC more often) and brokers/sellers tend to refrain from disclosing apartments with poorer energy performance (Frondel et al., 2019), not accounting for such differences might bias the results and thus our interpretations.

Table 4
Differences in EPC scores between owner-occupied and rental apartments.

	Dependent variable: ln(kWh/m^{2}a)			
	(1)	(2)	(3)	(4)
Offer Type (Base: Owner-Occupied)				
Renter-Occupied	0.121***	0.122***	0.015***	0.015***
	(0.003)	(0.003)	(0.002)	(0.002)
Rental Market	0.007***	0.000	0.043***	0.043***
	(0.002)	(0.002)	(0.001)	(0.001)
Number of Floors FE		Y	Y	Y
Building Year FE			Y	Y
EPC Type FE				Y
R^2	0.156	0.159	0.510	0.511
N	719,948			
# Zipcodes	6823			
Mean Score	111			

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for zip code and the last year and month in which the apartment was observed on the housing market. Number of Floors captures the size of the building. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.2. Main results

Table 4 reports estimated versions of the regression Eq. (1). First, we evaluate the differences in energy efficiency levels between owner-occupied and renter-occupied apartments for sale as well as apartments on the rental market over all broker types. The specification in Column (1) does not control for any building-specific variables, and the coefficients suggest that the EPC scores in renter-occupied apartments for sale are about 12 percent higher compared to owner-occupied apartments for sale. In turn, the difference between apartments for rent and owner-occupied apartments for sale is economically very small, amounting to merely 0.7 percent.

Column (2) shows that the inclusion of building size (measured by the number of floors) has only a negligible effect on the coefficients on both renter-occupied apartments for sale and those for rent. In contrast, the incorporation of building construction years in Column (3) absorbs a great deal of the differences in energy performance scores for renter-occupied apartments for sale. However, the coefficient on apartments for rent (*Rental Market*) increases noticeably. In this specification, the difference in EPC scores between renter-occupied and owner-occupied apartments for sale amounts to 1.5 percent, while the difference between apartments for rent and owner-occupied apartments amounts to 4.3 percent. It seems that a large part of the difference in EPC scores is explained by the year when the building was constructed. Hence, much of the estimated differences in energy efficiency may be due to the fact that owners are much more likely to move into new or largely refurbished apartments. Petrov and Ryan (2021) also report that fewer newly constructed properties are intended for renter-occupied housing. In the last column of the table, we find that differences in the type of energy certificate issued for the property do not notably change our estimates of interest.

Next, in Table 5 we focus on the differences in EPC scores across broker types using the specification in Column (3) from Table 4. Among direct offers from private individuals, we detect that statistically there is no difference between the energy efficiency level between renter-occupied and owner-occupied apartments for sale. In turn, our estimates suggest that the energy requirement of apartments on the rental market is about 2 percent higher and statistically significant than for owner-occupied apartments for sale. Given a mean EPC score of 110 (Table 1), this results in a difference of 2.2 kWh/m^{2}a. For comparison, an interval in the energy performance certificate spans 25 kWh/m^{2}a. To put the results in perspective: Given an average apartment size of 75 m^2 (Table 1) and the historical mean gas price of roughly EUR 0.06 per kWh, the additional monetary burden for rented apartments is 2.2*75*0.06 = EUR 10 per year.

Focusing on indirect offers through real-estate agents, we find that the energy requirement of renter-occupied apartments is 1.8 percent higher compared to owner-occupied apartments. However, the difference between apartments on the rental market and owner-occupied apartments amounts to about 6 percent. Using the average apartment size of 75 m^2, the mean EPC score (110 kWh/m^{2}a), and the historical average gas price of EUR 0.06 per kWh, the additional energy cost for such apartments amounts to EUR 30 (= 0.060 * 110 kWh/ m^2 * 75 m^2 * 0.06 EUR/kWh) per annum.

Based on the differences in EPC disclosure rates discussed in the previous section, offers by real estate agents are less likely to be contaminated by disclosure bias and we expect significant under-reporting by private brokers. Thus, the estimates for private brokers are likely underestimates while estimates for real estate agents serve as the upper bound. Given the much lower number of observations for renter-occupied apartments, we use the nearest neighbor matching estimator for better covariate support and as a robustness check of these results in Appendix C. Although the coefficient on *Renter-Occupied* apartments is now significantly higher, both estimates corresponding to direct offers from private brokers are likely underestimates due to underreporting of energy performance certificates. The estimates corresponding to offers through real estate agents are now closer together with a maximum difference of 6 percent between owner-occupied apartment and rental apartments.

Table 5
Differences in EPC scores by broker type.

	Dependent variable: ln(kWh/m^2a)	
	Private Seller	Real-Estate Agent
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.010	0.018***
	(0.007)	(0.002)
Rental Market	0.020***	0.059***
	(0.004)	(0.001)
R^2	0.544	0.520
N	183,574	535,360
Mean Score	112	111

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
First occupancy homes.

Panel A - Private Seller	Dependent Variable: ln(kWh/m^2a)	
	First Occupancy = 0	First Occupancy = 1
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.010	−0.044
	(0.007)	(0.076)
Rental Market	0.013***	0.053***
	(0.004)	(0.017)
N	152,670	20,792
R^2	0.507	0.736
Mean Score	114	93
Panel B - Real Estate Agent	Dependent Variable: ln(kWh/m^2a)	
	First Occupancy = 0	First Occupancy = 1
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.008***	−0.055***
	(0.002)	(0.020)
Rental Market	0.029***	0.101***
	(0.002)	(0.005)
N	390,188	73,251
R^2	0.447	0.721
Mean Score	116	79

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Panel A limits the seller type to private sellers and Panel B to real estate agents. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.3. Heterogeneity analysis

In this section, we evaluate energy efficiency differences between owner-occupied and rented apartments (renter-occupied for sale and apartments for rent) separately for different subgroups. First, we explore whether the estimated split-incentive deficit in energy efficiency performance varies between old and new buildings. To this end, we distinguish apartments that are on the market for first occupancy (i.e., either new construction or substantially reconstructed before coming on the housing market) and those that are not.

Table 6 summarizes the results. For the sub sample of existing apartments that were on the market (i.e., not for first occupancy), we estimate small differences (1 to 2.9 percent) in energy efficiency scores by tenure status. Moreover, the difference in energy efficiency levels seems to be larger when real-estate agents are involved as brokers (likely because of higher EPC disclosure rates).

The last column in Table 6 shows that for first occupancy buildings, the average EPC score of rental market properties is 5.3 percent higher compared to owner-occupied properties when the apartment is offered directly by a private individual and about 10 percent higher when the apartment is offered indirectly through a real estate agent. A reason could be that the top energy efficiency standards (A+ or A) tend to be priced at a significantly higher premium on the sales market, which may make them economically more suitable for self-use, rather than for rental income. Given an average apartment size of 75 m^2, the historical average gas price of EUR 0.06 per kWh, and mean EPC scores of 93 and 79 kwh/m^2a respectively (Table 6), these estimates translate to an additional cost of 22 EUR (first occupancy apartments from direct offers from a private broker) and 36 EUR (first occupancy apartments from

Table 7
Building codes.

Panel A - Private Seller	Dependent Variable: ln(kWh/m^{2}a)				
	Pre-1978	1978–1983	1984–1994	1995–2001	2002+
Offer Type (Base: Owner-Occupied)					
Renter-Occupied	0.013	0.035	0.023*	−0.017	−0.002
	(0.010)	(0.026)	(0.013)	(0.015)	(0.030)
Rental Market	0.011**	0.045***	0.021***	0.009	0.022*
	(0.005)	(0.013)	(0.007)	(0.009)	(0.011)
N	91,352	8,570	23,142	20,676	35,542
R^2	0.336	0.380	0.276	0.328	0.393
Mean Score	133	126	119	101	57
Panel B - Real Estate Agent	Dependent Variable: ln(kWh/m^{2}a)				
	Pre-1978	1978–1983	1984–1994	1995–2001	2002+
Offer Type (Base: Owner-Occupied)					
Renter-Occupied	0.009***	−0.003	0.026***	0.019***	0.036***
	(0.003)	(0.008)	(0.004)	(0.004)	(0.010)
Rental Market	0.043***	0.023***	0.026***	0.025***	0.062***
	(0.002)	(0.005)	(0.003)	(0.003)	(0.004)
N	286,348	23,083	57,515	60,464	104,506
R^2	0.388	0.489	0.456	0.343	0.456
Mean Score	130	122	114	102	62

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Panel A limits the broker type to private sellers and Panel B to real estate agents. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

indirect offers through real estate agents) per annum. Yet, compared to owner-occupied apartments, renter-occupied apartments that are on sale for the first time are somewhat more energy-efficient, as the difference amounts to 4.4 and 5.5 percent, depending on the broker type. However, only 2 percent of renter-occupied apartments for sale are listed as first occupancy (see Table 1), and this estimate likely draws from an unrepresentative or misclassified group of buildings because first occupancy homes by definition should be vacant.

To explore the role of building age further, we conduct additional building sub-group analyses by assessing buildings according to the stringency of the energy standards that applied when the property was constructed. We expect the split-incentive problem in energy efficiency to be higher in older homes, given weaker energy standards and thus a greater potential for improvements through renovations in owner-occupied properties. Also in this case, we distinguish between broker types. Contrary to our expectation, however, we do not find that the difference in EPC scores between owner-occupied and other apartments is systematically larger for older buildings, and this holds for transactions through both private individuals and real estate agents (Table 7).

Beyond assessing the potential energy efficiency deficits due to split-incentives at the national level, we are also interested in whether our estimates differ across regions.First, we assess the extent of the energy efficiency differences among the different offer types for three specific region types (urban, semi-urban, and rural). Unsurprisingly, the majority of the apartments observed on the housing market are located in zip codes that fall in urban or semi-urban regions (Table 8). The coefficients in the first and second columns suggest that, within urbanized regions, owner-occupied apartments for sale are significantly more energy-efficient on average than both renter-occupied apartments for sale and apartments for rent. This difference is even more pronounced when real estate agents are involved – a repeating pattern that is likely due to higher EPC disclosure rates. The third column indicates that in rural areas, apartments for rent, when sold through a real estate agent, exhibit somewhat higher EPC scores, i.e., lower energy efficiency, than owner-occupied apartments, but somewhat better energy efficiency levels when they are offered directly through private individuals. Again, this result is likely biased due to poor covariate common support and underreporting of EPCs when the apartments are offered directly by private individuals.

Next, we assess the heterogeneity with respect to a broader regional category, namely whether apartments are located in the east or west of Germany. This is important because the ownership structure of apartment units varies significantly between regions of Germany - a higher share of buildings in East of Germany are owned by private companies, public institutions, and housing cooperatives (Destatis, 2019), while there are more private individuals owning and renting property in the West. As we have learnt from the descriptive statistics, the share of renter-occupied housing units is much higher in East Germany, which also happens to have historically lower incomes and wealth in financial assets. Estimates reported in Table 9 suggest that the housing stock for renter-occupied apartments in East Germany that are sold through direct offers, i.e. by a private landlord, has somewhat higher energy efficiency levels (lower EPC scores) compared to owner-occupied properties. This estimate is likely biased downward as well due to lower compliance with the EPC disclosure requirement by offers made by private brokers.

For apartments in East Germany sold through real estate agents this does not hold, with energy efficiency levels being significantly and on average about 2 percent higher than for owner-occupied homes. The difference can even amount up to 6 percent when comparing apartments for rent with owner-occupied apartments. In West Germany, energy efficiency levels are higher for renter-occupied apartments for sale and apartments for rent both for direct and indirect offers with differences varying between 1.9 percent

Table 8
Spatial planning regions.

Panel A - Private Seller	Dependent Variable: ln(kWh/m^{2}a)		
	Urban	Semi-Urban	Rural
Offer Type (Base: Owner-Occupied)			
Renter-Occupied	0.015*	0.011	−0.045*
	(0.009)	(0.016)	(0.027)
Rental Market	0.019***	0.031***	−0.017
	(0.004)	(0.008)	(0.015)
N	126,018	41,440	15,853
R^2	0.517	0.585	0.607
Mean Score	115	107	103
Panel B - Real Estate Agent	Dependent Variable: ln(kWh/m^{2}a)		
	Urban	Semi-Urban	Rural
Offer Type (Base: Owner-Occupied)			
Renter-Occupied	0.012***	0.043***	0.008
	(0.003)	(0.005)	(0.007)
Rental Market	0.054***	0.072***	0.042***
	(0.002)	(0.003)	(0.005)
N	348,647	132,152	53,388
R^2	0.514	0.528	0.590
Mean Score	113	109	105

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Panel A limits the broker type to private sellers and Panel B to real estate agents. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
East-West divide.

Panel A - Private Seller	Dep. Variable: ln(kWh/m^{2}a)	
	East	West
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	−0.032**	0.019**
	(0.015)	(0.008)
Rental Market	−0.012	0.020***
	(0.009)	(0.004)
N	21,755	161,789
R^2	0.480	0.555
Mean Score	107	113
Panel B - Real Estate Agent	Dep. Variable: ln(kWh/m^{2}a)	
	East	West
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.017***	0.028***
	(0.003)	(0.003)
Rental Market	0.060***	0.046***
	(0.002)	(0.002)
N	216,786	318,539
R^2	0.417	0.593
Mean Score	105	115

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Panel A limits the seller type to private sellers and Panel B to real estate agents. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

and 4.6 percent. Interestingly, these results may square well with a sub-result shown by Petrov and Ryan (2021), who find smaller differences in the energy efficiency performance of homes by offer type in regions with higher shares of rental properties. This could explain why we see on average across both offer and broker type larger and significant estimates in West Germany, where home ownership is significantly higher.

Finally, we investigate the heterogeneity with respect to purchasing power. We utilize data on the purchasing power per household in 2019 from RWI and microm (2022), aggregated at the zip code level. To examine whether there is significant socioeconomic heterogeneity in the average estimates, we map each zip code to its respective tercile of the purchasing power

Table 10
Purchasing power per household and East-West divide.

Panel A - Private Seller	Dependent Variable: ln(kWh/m^{2}a)		
	Tercile 1	Tercile 2	Tercile 3
Offer Type (Base: Owner-Occupied)			
Renter-Occupied	0.006	0.005	0.020
	(0.012)	(0.013)	(0.014)
Rental Market	0.018***	0.024***	0.017***
	(0.006)	(0.006)	(0.007)
N	62,587	60,294	58,445
R^2	0.447	0.564	0.588
Mean Score	118	113	105
Panel B - Real Estate Agent	Dependent Variable: ln(kWh/m^{2}a)		
	Tercile 1	Tercile 2	Tercile 3
Offer Type (Base: Owner-Occupied)			
Renter-Occupied	0.013***	0.037***	0.023***
	(0.003)	(0.004)	(0.005)
Rental Market	0.061***	0.056***	0.040***
	(0.002)	(0.003)	(0.003)
N	279,407	135,586	109,800
R^2	0.441	0.580	0.624
Mean Score	111	113	109

Notes: The dependent variable is the log of the reported energy performance score measured in annual kWh per square meter of living space. All regressions included fixed effects for building size (number of floors), year of construction, the zip code, and the last year and month in which the apartment was observed on the housing market. Panel A limits the seller type to private sellers and Panel B to real estate agents. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

distribution and estimate our preferred specification for each tercile separately. We find that compared to owner-occupied apartments, apartments for rental purposes are slightly less energy-efficient when the apartment is sold or offered on the rental market directly through a private landlord, and this difference is similar across all income terciles. For renter-occupied apartments directly offered through a private landlord, the differences are not statistically significant. However, when real-estate agents are involved, we see larger and statistically significant differences. For renter-occupied apartments, the divergence amounts to almost 4 percent in the second tercile (Table 10). The difference is even larger for apartments on the rental market, ranging from 6 percent in the first tercile to 4 percent in the third and highest tercile. Hence, our results suggest that apartments rented out in regions within the lowest income group through real estate agents are particularly less energy-efficient than owner-occupied homes.

6. Conclusion

It is often argued that landlords may underinvest in energy efficiency because, unlike owner-occupants of homes, they do not benefit from cost savings triggered by energy efficiency when their tenants pay the energy bills directly. This problem may be particularly acute in the German multi-apartment building sector, where private individuals own roughly 60% of housing units, of which 70% are rented out, predominantly with tenant-pay contracts. However, housing property owners can reap the economic benefits from investing in energy efficiency, if it is sufficiently capitalized during sale on the housing market or by increasing rents on long-term contracts.

We have analyzed data from Germany, home to one of the largest rental housing markets in the European Union. In our analysis, we find small and economically insignificant average differences (up to 6 percent) in energy performance scores between buildings with owner-occupied apartments for sale and rental apartments (renter-occupied for sale and apartments for rent). Despite this overall small difference for Germany, we find some heterogeneity. For instance, energy efficiency differences are much higher in new (or completely renovated) buildings when comparing apartments for rent and owner-occupied apartments for sale. Moreover, we detect that in urban and less wealthy areas, the gap in energy efficiency between owner-occupied apartments for sale and apartments for rent is higher compared to rural and wealthier regions. Last, we detect notables differences in estimates across broker types, as transactions through real estate agents who act on behalf of private individuals are associated with larger gaps in energy efficiency compared to transactions through private individuals. This is likely explained by the fact that real estate agents have significantly higher compliance rates (more than twice the rate in the rental market). Overall, in economic terms the EE difference is still moderate as it amounts up to 6 percent. Given an average apartment size (75 m^2), EPC score (110 kWh/m^2) and historical average gas prices (EUR 0.06/kWh), the additional burden paid by tenants amounts to roughly EUR 25 per year.

Our findings have important implications for climate policy targeting the building stock. The absence of large differences in energy efficiency between renter-occupied and owner-occupied properties on the housing market indicates that properties that are looking for new owners or tenants should be less of a policy concern. A potential explanation for such low differences may also be related to a general unwillingness to renovate housing units to higher standards among homeowners in Germany, as evidenced by the consistently low rate of energy retrofits of only about 1%.

This paper, however, does not necessarily provide evidence of a similarly small deficit in existing long-standing rental properties, which are likely not to be well-represented in our data sample. Our data set only contains apartments that are on the market for a new owner or tenant, and, more specifically, were observed on the ImmoScout24 website. Even though it is the largest online broker of Germany and thus a highly valuable source of data, we thereby necessarily disregard two important segments of the housing market: first, the share of transactions that take place via other channels and second, the share of the housing market that is not involved in any market transaction. Put differently, we do not observe existing rental properties that do not exchange ownership hands and thus are not observable on the housing market. Notwithstanding, properties that do not make it back on the housing market are arguably harder to target for policy makers.

CRediT authorship contribution statement

Puja Singhal: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Stephan Sommer:** Writing – review & editing, Writing – original draft, Validation, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Kathrin Kaestner:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Michael Pahle:** Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Figures and tables

See Figs. A.1, A.2 and Tables A.1–A.6.

Table A.1
Distribution of the building stock by ownership.

	Total Apartment Units	Of which				
		Owner-Occupied	On Rent, of which: Owner is a			
			Private Person	Private Company	Public Institution	Housing Cooperative
	in 1000s					
Housing Type						
Detached House (1 HH)	11874	10501	1211	62	46	53
Semi-Detached House (2 HH)	5720	3362	2218	60	30	50
Building with 3-9 Apts	12344	2403	5895	1377	285	2383
Building with 10 or more Apts	6989	894	2178	1482	342	2093
Total	36927	17159	11503	2982	703	4580

Notes: The table shows the national distribution of the building stock in Germany by ownership and housing type. The housing units highlighted in blue are homes that are owner-occupied by private individuals, while the housing units highlighted in green are homes that are owned by private individuals but rented out on the housing market. This table is reproduced from the Microcensus 2018 (Destatis, 2019), translated from German to English.

Table A.2
Share of privately-owned housing units on rent.

Housing type	Share
Houses	
Detached and Semi-Detached Units	20%
Multi-Apartment Buildings	
with 3–9 Apt Units	71%
with 10+ Apt Units	71%
All	40%

Notes: The table reports the share of German housing units (apartments) in each housing type that were owned by private individuals and rented out. Data sourced from the Microcensus 2018 (Destatis, 2019).

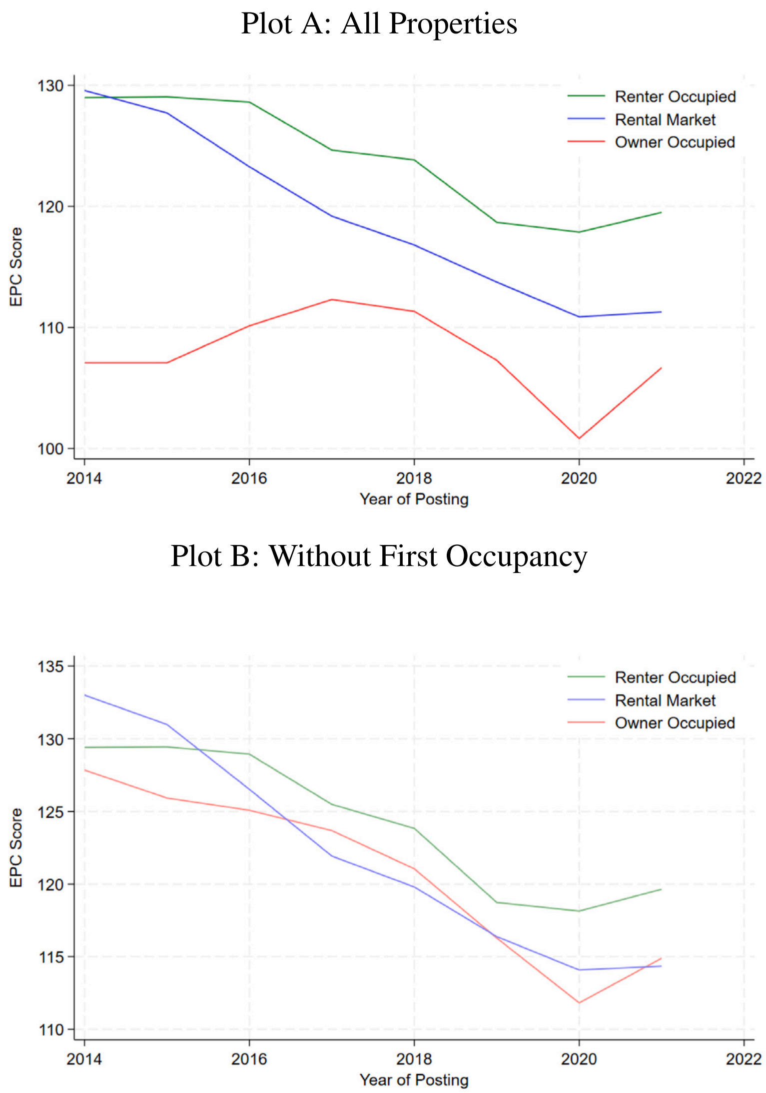
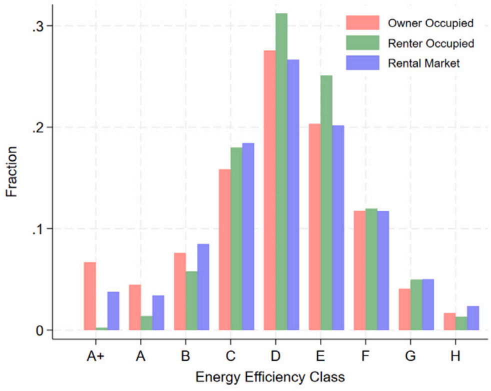
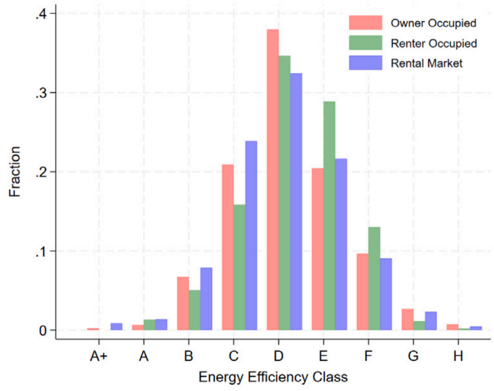


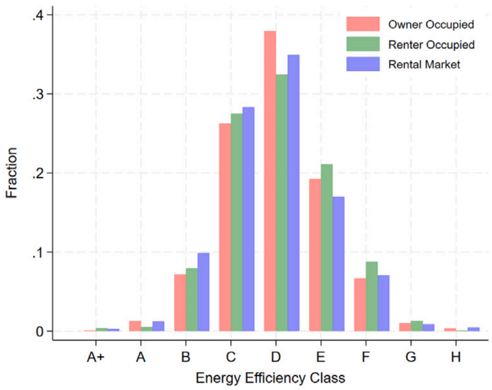
Fig. A.1. Differences in EPC Scores by Type of Apartment Offer.
Notes: The graphs plot the average EPC score of buildings by the year apartment was offered on the housing market, by all broker types. We differentiate between owner-occupied for sale, renter-occupied sale and apartments for rent. Plot A uses data for apartments observed from May 2014 to 2021, while Plot B limits the sample to those apartments that were not identified as "First Occupancy" or "First Occupancy after Reconstruction".
Plot A shows that (1) there are minor differences between the mean energy performance of properties that were directly on the rental market and those that were bought as investment property to make rental income in 2014, but this difference has grown, and (2) owner-occupied apartments were more energy-efficient than rental apartments on average. In Plot B, the differences between owner-occupied and rental properties shrink significantly, once we remove apartments looking for first occupants from the sample.



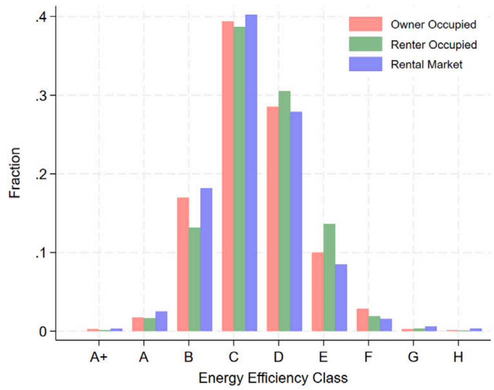
(a) Pre-1978



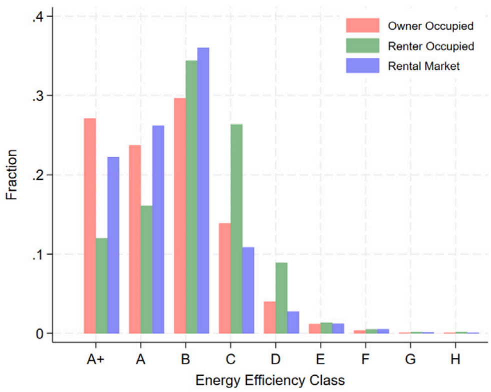
(b) 1978-1983



(c) 1984-1994



(d) 1995-2001



(e) 2002+

Fig. A.2. Distribution of EE classes by building codes.
Notes: The graphs summarize the distribution of building-level energy efficiency class/grade grouped by year of construction brackets associated with building codes.

Table A.3
Standards for new construction.

Year of construction	Regulation	Max. per annum
Pre-1978	No regulation	
1978	Heat insulation (WSchV)	250 kWh/m^2a
1984	Amendment of WSchV	220 kWh/m^2a
1995	Amendment of WSchV	150 kWh/m^2a
2002	Energy saving (EnEV)	100 kWh/m^2a
2009	Amendment of EnEV	60 kWh/m^2a
2016	Amendment of EnEV	45 kWh/m^2a
2020	Building Energy Act (GEG)	35 kWh/m^2a

Notes: The table shows the progression of minimum energy performance requirements for newly constructed buildings in Germany.

Table A.4
Energy efficiency of rental apartments by offer source.

	Mean	s.d.	N
Private Offer			
EPC Score	112	52	187,537
Year of Construction	1973	38	187,537
Real-Estate Agent			
EPC Score	110	51	608,084
Year of Construction	1966	43	608,084
Housing Industry			
EPC Score	113	48	814,129
Year of Construction	1966	31	814,129

Notes: The table highlights differences in the EPC score (kWh/m^2a) and vintage of properties on the rental market by the source of apartment on offer.

Table A.5
Energy efficiency differences by EPC type and building codes.

Energy Demand Certificate			
	Apartment Purchase		
	Owner-Occupied	Renter-Occupied	Rental Market
Pre 1978	127	144	138
	(67)	(57)	(66)
	26,367	7,699	87,057
1978–1983	132	128	125
	(44)	(40)	(45)
	1,571	317	5,178
1984–1994	121	120	123
	(41)	(33)	(44)
	2,932	1,021	10,011
1995–2001	104	104	106
	(35)	(31)	(36)
	2,017	1,038	8,888
2002+	52	60	56
	(28)	(31)	(30)
	18,602	1,212	89,925
Energy Use Certificate			
	Apartment Purchase		
	Owner-Occupied	Renter-Occupied	Rental Market
Pre 1978	126	124	129
	(38)	(37)	(41)
	49,849	20,548	187,501
1978–1983	122	122	122
	(37)	(35)	(38)
	6,440	1,795	18,023
1984–1994	114	117	114
	(33)	(33)	(35)
	14,913	5,736	47,893
1995–2001	101	101	101
	(30)	(27)	(30)
	12,448	7,366	51,295
2002+	78	82	81
	(31)	(29)	(38)
	6,532	1,400	23,903

Notes: The table reports summary statistics (mean, standard deviation in parentheses, and the number of observations) for the reported energy performance scores (kWh/m^{2}a) by the type of energy performance certificate and building codes categories.

Table A.6
EPC compliance by real estate agents.

	$y = \mathbb{1}(EPC\ available)$	
	(1)	(2)
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.070***	0.059***
	(0.002)	(0.002)
Rental Market	0.078***	0.084***
	(0.001)	(0.001)
Year of Construction (Base: Pre 1978)		
1978–1983		0.086***
		(0.003)
1984–1994		0.128***
		(0.002)
1995–2001		0.140***
		(0.002)
2002+		0.004***
		(0.001)
Number of Floors in Building (Base: 0–1 Floors)		
2 Floors		0.007**
		(0.003)
3 Floors		0.015***
		(0.003)
4 Floors		0.030***
		(0.003)
5 Floors		0.062***
		(0.003)
6+ Floors		0.089***
		(0.003)
Observations	733,539	733,539
R^2	0.111	0.126

Notes: The table presents estimated versions of Equation (1), when limiting the broker type to real estate agents. The binary dependent variable indicates whether the EPC issued for the building was available in the real estate apartment advertisement. The coefficient estimates on the year of posting and the month of posting were omitted for readability purposes. All specifications included zip code fixed effects. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix B. Energy efficiency premium

Aiming to uncover the potential financial advantages of energy efficiency investments, we test for whether higher energy performance standards as measured by EE class labels (A+ to H) are associated with energy efficiency premiums on the housing market. A caveat of this exercise is that we only observe asking sale prices and rent in our data. Notwithstanding, asking prices are good proxies for transaction prices as documented by Frondel et al. (2019).

Using our estimation sample, we test for energy efficiency premiums separately by tenure type of the apartment in Table B.1. The first column highlights that compared to apartments with A+ rating, apartments seeking new owner-occupiers with lower energy efficiency performances are generally sold for a discount, which increases as the energy efficiency class decreases. The coefficients in the second column indicate a similar pattern for renter-occupied apartments as well, although these estimates are by and large statistically insignificant. The third column explores whether the energy efficiency premium is reflected in asking rents (excluding heating costs) for apartments seeking new tenants. Overall, the estimates suggest that the rent premiums for higher energy performance standards are smaller in the rental market than that in the market for sale. This finding is consistent with most recent work by Sieger and Weber (2023) and Galvin (2024), who explore price premiums for higher energy efficiency standards in the market for rental apartments.

Table B.1
Energy efficiency premiums.

	Dependent variable		
	ln(asking price/m^2)		ln(asking rent/m^2)
	(1) Owner-occupied	(2) Renter-occupied	(3) Rental market
EE Class (Reference: A+)			
A	−0.018	−0.017	−0.006
	(0.012)	(0.043)	(0.004)
B	−0.024**	−0.013	−0.003
	(0.011)	(0.040)	(0.004)
C	−0.027***	−0.013	−0.011***
	(0.010)	(0.039)	(0.004)
D	−0.040***	−0.039	−0.018***
	(0.010)	(0.039)	(0.004)
E	−0.055***	−0.030	−0.022***
	(0.010)	(0.039)	(0.004)
F	−0.059***	−0.074*	−0.005
	(0.012)	(0.040)	(0.005)
G	−0.086***	−0.065	−0.020***
	(0.016)	(0.042)	(0.006)
H	−0.078***	−0.075	0.005
	(0.024)	(0.056)	(0.009)
Unknown	−0.053***	−0.051	−0.019***
	(0.009)	(0.038)	(0.003)
N	140,803	47,260	529,081
R^2	0.775	0.857	0.805

Notes: The dependent variables for the first two columns is the log of asking price per square meter of living space and the log of cold rent per square meter of living space for the third column. All regressions included fixed effects for broker type, building size (number of floors), year of construction, the zip code, and the first year and month in which the apartment was observed on the housing market. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix C. Robustness check

We turn to checking the robustness of our main estimation that uses fixed effects to control for differences in location and building-level attributes. Now we employ the nearest-neighbor matching (at least one neighbor) estimator to create comparison groups such that covariate distributions are as similar as possible, using the Mahalanobis distance metric in computing differences between pairs of observations. The covariates specified were identical to those in the original specification: year of construction, building size, latitude and longitude coordinates for the zip code, and exact match for the broker type (private or real estate agent) and state in which building is located. Table C.1 shows estimates that compare the listings of owner-occupied and renter-occupied properties for sale in column (1). Column (2) compares owner-occupied properties for sale with rental market listings. The estimates are much closer to each than those using fixed effects estimator to control for differences in the covariate support, likely because the matching estimator forces stronger common support and relies less on the linearity assumption. Both results are consistent with the qualitative result that the differences in energy efficiency by tenure type are significant but small in economic terms (up to 6%).

Table C.1
Nearest-neighbor matching estimator.

Panel A - Private Seller	Dependent Variable: ln(kWh/m²a)	
	(1)	(2)
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.027***	
	(0.003)	
Rental Market		−0.002
		(0.005)
N	16,918	180,144
Panel B - Real Estate Agent	Dependent Variable: ln(kWh/m²a)	
	(1)	(2)
Offer Type (Base: Owner-Occupied)		
Renter-Occupied	0.055***	
	(0.003)	
Rental Market		0.049***
		(0.003)
N	189,820	490,360

Notes: The table reports estimates from nearest-neighbor matching on building size (number of floors), year of construction, latitude and longitude coordinates of the zip code, and exact match on German state in which the building is located, using the Mahalanobis distance metric. Panel A limits the seller type to private sellers and Panel B to real estate agents. Abadie-Imbens standard errors reported. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Data availability

The primary database used in this research is publicly available for scientific research at https://fdz.rwi-essen.de/.

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