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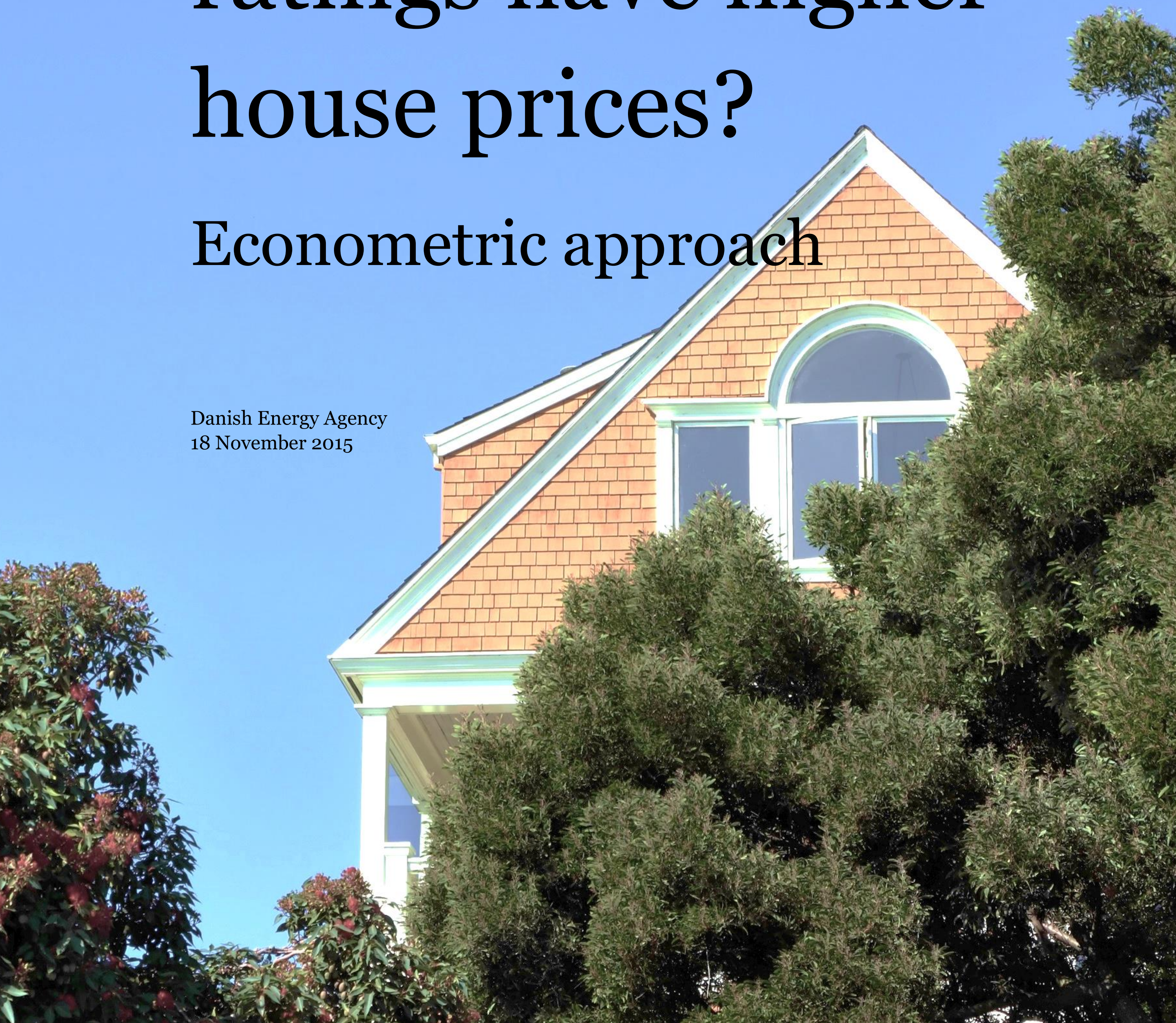
Copenhagen Economics

Do homes with better energy efficiency ratings have higher house prices?

Econometric approach



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Copenhagen Economics

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Preface

Copenhagen Economics was commissioned by The Danish Energy Agency to examine the relationship between house prices and energy standards. The analysis comprises both an econometric and an experimental approach. The final result is presented in three separate reports: One on results and methods from the econometric approach, another on results and methods from the experimental approach and a third summarizing the key results from both studies. You are now reading the report on results and methods from the econometric approach.

This background report explains in detail the methods we applied within the econometric part and presents our results. First, we set up a framework to assess how Danish energy standards should affect house prices in theory, if buyers are fully rational and informed and if markets are perfect. Thereafter, we use three different types of econometric models to assess the effect of the energy standard on the house price in general. In the end, we analyse more specific effects on energy standards depending on energy price, renovation potentials, markets and buyers.

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Chapter 1
Introduction and summary

In Denmark, it is mandatory to report the housing energy standard when selling a house. This provides houses with a label on an A-to-G scale, where A indicates the highest energy standard and G indicates the lowest. In doing so, housing buyers have a simple way to evaluate the costs of heating related to houses they consider buying, and for typical families, the potential savings can be quite substantial.

Using Danish register data analysis, this paper questions to what extend energy standards affect house prices. Essentially, we ask whether housing buyers' willingness to pay for energy standards adds up with the related value of the future energy savings. This is a critical question, since if the energy efficiency of houses are under-priced it can involve a social non-optimal situation where entrepreneurs and existing homeowners have an – seen overall – irrational low incentive to build and renovate houses for obtaining a high energy standard.

This is not a trivial question. The selling price of a house is determined by a range of characteristics and circumstances, which give rise to two key complicating issues. First, houses of higher energy standards are also typically newer and in better state of maintenance. Similar to energy standard, such conditions have positive effects on the house price, which makes it difficult to disentangle the "clean" price effects of energy standards. Secondly, when we observe a house for sale with a given energy standard, it is an outcome of a range of decisions made by the seller, given his or her possibilities at the time. Neither the possibilities nor decisions can be considered random in relation to the expected selling price. Hereby we should be careful when interpreting the simple relation between energy standards and selling prices. It may often be the case that the expected house prices for given energy standards affect housing owners decision whether or not energy renovate and whether or not put their house for sale.

To overcome these issues, we analyse Danish house prices using highly detailed register data on all (300 thousand) single family houses sold in Denmark from 2006 to 2014. As our key variables, this data includes the sales price of all houses as well as the energy standard for houses, where stated in the sales ad. The data also includes various other characteristics related to houses: the size and structure of the house, the year of construction, state of maintenance, building materials and geographical distance to the water, bigger roads etc. The data also includes information related to the specific sale: the general sales price of houses in the area at the time of sale, as well as different buyer and seller characteristics. This allows us to control for a great number of details related to each sale and thereby to a large extent rule out other causal mechanisms beside the one we are looking for.

Further, we test our question on the data using three different types of statistical models: a random effects, a fixed effects and a matching model. All models approach the question from slightly different perspectives, and we apply several robustness tests to try to overcome the two complicating issues described above. Finally, we recognize that the pricing of energy standards – in contrast to the price effects related to other housing conditions – should depend on the expected future energy savings and, hence, energy prices. Since energy prices varies a lot, we expect to find large variations in the pricing of energy standards depending on the type of heating and energy prices at the time of sales.

We have divided the rest of the paper into five chapters. In Chapter 2, we take a purely theoretical perspective to get an understanding and indication of what to expect from our econometric results.

Knowing the expected energy consumption related to houses of each Danish energy label (A-to-G) as well as the average energy price, we are able to calculate the expected yearly energy savings in kr. per sq. m. Given certain assumptions about rational buyers' preferences, expectations and options to energy renovate, expected energy savings capitalize into a higher price of energy efficient houses. Overall, for a 100 sq. m. house, we find a price premium of 149,000 kr. for every 10 MWh in yearly energy savings. This corresponds to 100 kWh per sq. m., which equals the difference in average energy consumption between a E-labelled and a B-labelled house.

We also find that energy prices, heating types and the option to renovate should be crucial to the pricing of current energy standards. For a 100 sq. m. house, the price premium per 10 MWh yearly energy savings should increase by 68,000 kr. when energy prices increase by 1 kr. per kWh. Further, a potential option to energy renovate decrease the pricing of current energy standards significantly.

In Chapter 3 we present our data, the three econometric models and show how they are able to resolve the typical statistical problem related to our research question.

Chapter 4 presents our baseline result. Here we find that energy standards have clear and significant influence on house prices, no matter the number of control variables included in our statistical models. That said, our results indicate that energy standards are closely correlated with the building year and general condition of houses. In our main and most detailed model, we find significantly higher price effects for every higher energy standard going from G to B, and the relative price effects follows the energy savings related to each label quite closely. Only in the last step, from B to A, the estimated price difference is not statistically significant. However, this can be attributed to a relatively small difference between the expected energy saving of an A compared to a B-labelled house, as well as a small sample of houses sold having an A-label.

Looking across all energy labels, our most robust model indicate that higher energy standards increase the selling price of a 100 sq. m. by 92,700 kr. for every 10 MWh in yearly energy savings. The estimates are very significant, robust and relatively similar across our three statistical models. Looking across all three models, and controlling for outliers, sample selection problem etc., the models indicate a price effect for a 100 sq. m. house between 81,000 and 118,300 kr. for every 10 MWh in yearly energy savings.

These estimates are between 50 and 25 per cent below our theoretical expectations, and this could indicate that housing buyers are either short sighted, credit restricted or simply uninformed about the meaning of energy standards.

In Chapter 5 we extent the model in different directions. First, we analyse how the pricing of energy standards vary with energy prices. For a 100 sq. m. house, the price premium increases by 39,200 kr. when energy prices increase by 1 kr. per kWh. This is statistical significant and robust across various specifications and statistical models. Since the pricing of other housing characteristics should not depend on energy prices, this is a critical robustness test of our main model results, and it tend to reject that the results are driven by omitted variable bias. That said, the estimates are about 40 per cent below our theoretical expectations, similar to the main model results. We also find that energy standards have increase over time, at least partly because of the increasing energy prices.

Secondly, we analyse the heterogeneity across different housing characteristics. When we control for options to renovate we find no significant price effect of the option to renovate and no significant changes in the pricing of current energy standards. This is a bit puzzling, but it could be because the option to renovate typically is higher for houses in poor conditions. That said, we do find that energy standards matter more for houses build between 1930 and 1960 compared to houses build before and after. This could result from the fact that houses build before 1930 typically have large potentials for energy renovations.

Thirdly, we analyse how the effects vary across regions and different types of buyers. Here, the results indicate that the pricing of energy standards is significantly higher in the capital region, generally high for high-income families but also quite high for families in the lowest income group. Similar results are found when conditioning on house prices, where the pricing of energy standards are highest for high- and low-price houses, and lowest for middle-price houses. This result are in line with regional heterogeneity, given the fact the both income and house prices are highest in the capital region. This indicates that buyers have different constants, information available or different preferences for current vs. future savings. In order to understand why the pricing of energy standards deviate from the theoretical expectations of a rational buyer, this will be an obvious field for further future analyses.

In the last Chapter 6, we compare our results to the earlier literature. A couple of earlier papers have analysed the effects of energy standards on housing prices in Denmark and other countries. Compared to these, the current study is more theoretical founded, we attach an exact energy consumption measure on each energy label, and we compare with the expected pricing of energy standards given rational housing buyers. Further, none of the earlier papers analyse the implications of changing energy prices.

The earlier papers only focus on the effects of the energy labels A to G, without any discussion about the meaning of the labels in terms of actual energy consumption. Therefore, the results of the papers are difficult to compare – with the exception of one earlier Danish study. Compared to the one Danish study done by SBi (2013), our results indicate somewhat lower effects of energy standards on house prices. This is probably resulting from the fact that SBi (2013) do not control for the general condition of houses, such as the number of errors and omissions. Compared to the other studies, it seems that Danish energy standards have close to the same effects on house prices as Dutch and Irish energy standards, but somewhat higher effects compared to UK energy standards (see Fuerst et al. (2015), Hyland et al. (2013) and Brounen and Kok (2010)).

Chapter 2

Theoretical hypotheses

From the economic theory on housing markets, the price of a house is determined by a number of characteristics and circumstances – what we call *price determinants*. These include geographic characteristics related to the location of the house: the region and neighbourhood, the view from the house and the distance to various attractions and possibilities. They include socioeconomic characteristics related to the buyer and, more broadly, the general economic conditions at the time of sale. Finally, they also include characteristics related to the housing construction, such as the construction year, size and structure as well as the materials and maintenance of the house.

As part of the housing construction, the price determinants also include the energy efficiency, heating type and other factors affecting the expected cost of heating. When buying a house, people should rationally weigh the cost of buying the house against the different housing characteristics, including the expected cost of heating the house. Our key question is how housing buyers value these factors against each other.

In this chapter, we briefly explain the workings of the Danish labelling system. Thereafter, we consider the view of a rational housing buyer, to understand how and why energy standards and heating types affect house prices. In the end, we do some hypothetical calculations to quantify to what extent energy standards should affect house prices, given standard assumptions about rational agent preferences, expectations etc.

2.1 Measures of energy standards and energy consumption

In this paper, we generally recalculate our results so they relate to a typical house of 100 sq. m. Further, we measure energy efficiency in two ways:

1. We will use the individual labels from the Danish energy labelling system (A to G). This gives a clear, intuitive and well-known indication about the energy consumption of a house, and we are able to analyse whether energy efficiency is valued higher for high energy efficient houses compared to low energy efficient houses.
2. As a more broad measure, we simply measure it by the expected yearly energy savings compared to a G-labelled house (in kWh per sq. m.).

In Denmark, official energy labelling of single-family houses was introduced in 1997. This system was refined later on, and from 2010 it became mandatory to report the energy label when selling a house. In this paper, we use the newest energy labelling system.[1] The labelling system entails that an energy consultant inspects the house and assigns a label on a scale from A to G, where A indicates the highest energy standard and

[1] Energy labels from previous labelling system are converted to the newest.

G the lowest.[2] Additionally, the consultant quantifies and describes obvious renovation possibilities to save energy.

Each energy label relates to a certain threshold of expected energy consumption for a standard family, depending on the size of the house. Table 1 shows the official thresholds, the thresholds for a typical house of 100 sq. m. and the related average energy consumption for each label.[3] As seen, a C-labelled house of 100 sq. m. has an energy consumption between 92 and 142 kWh per sq. m. per year – on average equal to 117 kWh per sq. m. per year. Compared to a 100 sq. m. house, smaller houses have a slightly higher energy consumption per sq. m. for a given energy label and larger houses have a slightly lower.[4]

Table 1 Danish energy labels, thresholds and average energy consumption

Yearly kWh/m²	Official thresholds	Threshold for a 100 m² house	Average levels	Average levels for a 100 m² house
A	≤ 52.5 + 1650/sq. m.	≤ 69	41.25 + 1325/sq. m.	55
B	≤ 70.0 + 2200/sq. m.	≤ 92	61.25 + 1925/sq. m.	81
C	≤ 110 + 3200/sq. m.	≤ 142	90 + 2700/sq. m.	117
D	≤ 150 + 4200/sq. m.	≤ 192	130 + 3700/sq. m.	167
E	≤ 190 + 5200/sq. m.	≤ 242	170 + 4700/sq. m.	217
F	≤ 240 + 6500/sq. m.	≤ 305	215 + 5850/sq. m.	274
G	> 240 + 6500/sq. m.	> 305	240 + 6500/sq. m.	335

Note: The official thresholds are from September 8, 2013. For the average level, we simply use the average of the threshold values of the given label and the label one-step higher. For G we do a similar calculation using a lower threshold of "≤ 290 + 7500/sq. m.", where we implicitly assume that the relation between the lower threshold of label F and G follow the same pattern as between E and F. For label A the average levels are based on an average of the A2010 and A2015 level. Here, sq. m. indicates the size of the heated area of the house.

Source: Copenhagen Economics based on http://boligejer.dk/energimaerkeberegningen

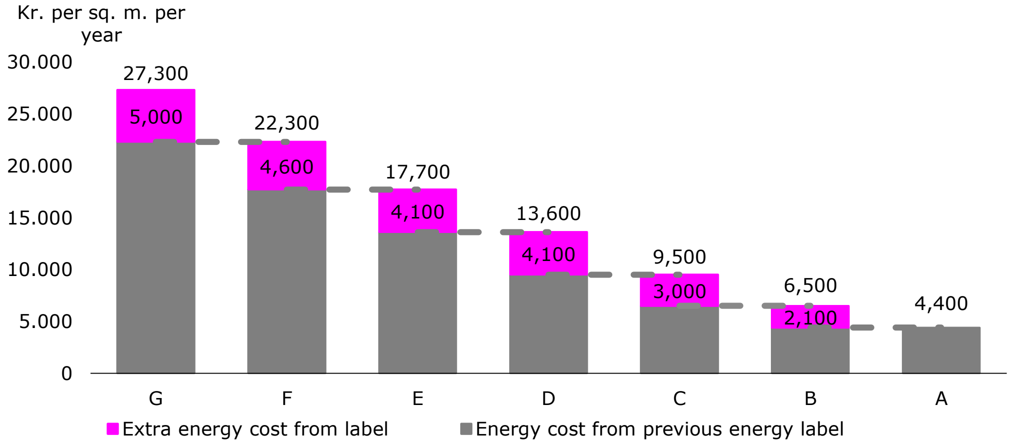
From a theoretical point of view, housing buyers do not focus on the energy consumption per se, but the cost of heating it gives rise to. This also depends on the type of heating and more specifically the price of energy per kWh at the given point in time. If we first consider a standard Danish house of 100 sq. m. with average energy prices, the yearly energy cost for a D-labelled house are approximately 4,100 kr. higher than for an equivalent C-labelled house, see Figure 1. In addition, it is clear that the savings related to each additional step up in energy label are bigger for low energy efficient houses.

[2] The A label is divided into three sublabels: A2020, A2015 and A2010. However, we do not have enough data on houses with different A-labels to quantify the price effect in such details, and therefore we will consider all as simply A-labelled. The labelling system has been modified through the years, but we have converted the historical labels into the most recent labelling system.

[3] The thresholds and average energy consumption for a 100 m² are quite close (a bit lower) than the average numbers we get when considering all houses sold in Denmark 2006-2014 (our sample).

[4] For example, a C-label house of 100 m² has an average energy consumption of 117 kWh per m², while this number is 135 kWh per m² for a house of 60 m² and 104 kWh per m² for a house of 200 m².

Figure 1 Yearly heating costs for the different energy labels given average energy prices



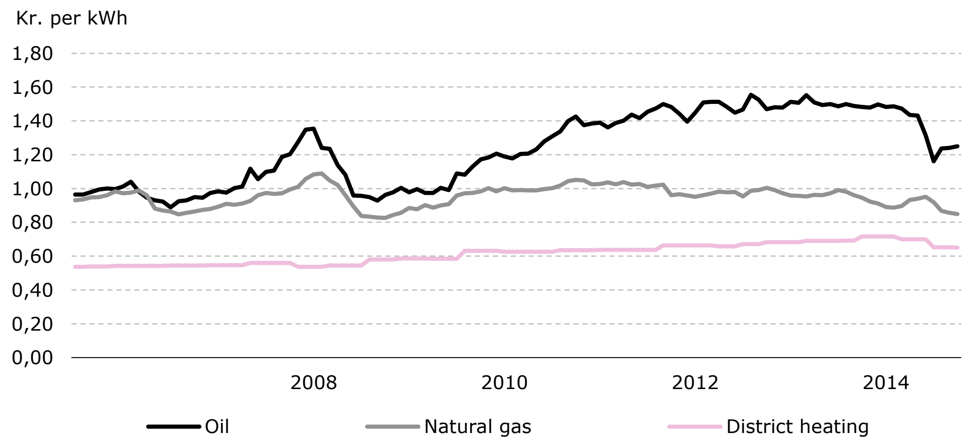
Note: Here we use average energy prices of 0.69 kr. per kWh, we consider a house of 100 sq. m. and each energy label refers to the average energy consumption within the threshold. All numbers a rounded to nearest hundred.

Source: Copenhagen Economics

In Denmark, modern houses typically use either district heating, natural gas or oil. As seen from Figure 2, the price of heating from these energy sources varies quite a bit, both across time and across type of heating. This gives rise to large variations in the cost of heating for a standard house. From 2006 to 2014, the average heating cost of a C-labelled 100 sq. m. house were 14,400 kr. yearly if heated by oil, while only half of that if using district heating, see Table 2. Given the time series variation in energy prices as seen in Figure 2, the cost of heating for each heating type also vary quite a bit from year to year.

In general, Danish energy labels give relatively clear indications about the energy consumption of houses, but the actual costs of heating also depend on the heating type, the price of energy and the size of the house.

Figure 2 Energy prices for typical types of heating



Note: The figure shows consumer prices including taxes

Source: Statistics Denmark and Danish Energy Agency

Table 2 Yearly heating costs for a house of 100 sq. m. depending on energy label and heating type

Kr. per year	District heating	Natural gas	Oil	Weighted avg.
A	3,400	5,200	6,700	4,400
B	4,900	7,700	9,900	6,500
C	7,200	11,200	14,500	9,500
D	10,300	15,900	20,600	13,600
E	13,300	20,700	26,800	17,700
F	16,800	26,100	33,800	22,300
G	20,600	31,900	41,400	27,300

Note: We use the average energy prices throughout our sample from 2006 to 2015 for each of the three energy sources (see Figure 2). In the "weighted avg." column to the right, we weight by the distribution of heating types in our sample. All numbers a rounded to nearest hundred.

Source: Copenhagen Economics

2.2 The view of a rational buyer

A simplified economic perspective

From an economic perspective, higher energy standards should affect house prices positively, as rational buyers are willing to pay more for houses today that allow them to save money on their heating bills in the future. Further, buyers may also (themselves) expect a higher future selling price when the house has a higher energy standard. We say that the future expected energy savings and selling price are capitalized in the price of the house today (see Box 1).

Box 1 Mathematical expressions of the value of energy efficiency

We consider "rational housing buyers" with a constant subjective discount rate and a constant expected growth in future energy prices. Further, we (for now) assume that the houses cannot change energy standards (renovate), buyers have an infinite investment horizon and we ignore depreciations.[5] Hereby, the relative capitalized value per sq. m. of having an energy efficient house (compared to a non-energy-efficient) should equal the discounted future expected energy savings:

$$V_t^{ee} = \frac{1}{\rho - g} ES_t, \quad (1)$$

where ES_t is the nominal energy savings per sq. m. for an energy efficient house at the time, g is the constant expected growth rate for nominal energy prices (savings) and ρ is buyers' constant subjective discount rate. In principal, ES_t should be measured in kr. saved per sq. m., and (1) shows that energy efficiency (energy savings in kr. per sq. m.) should affect the value in kr. per sq. m., i.e. in absolute terms.6 This means that, if a house allows for ES_t kr. per sq. m. in current yearly energy savings the sales prices should on average be V_t^{ee} kr. higher per sq. m.

Source: Copenhagen Economics

For potential buyers, the willingness to pay for higher energy efficiency of a given house – which potentially can capitalize in a higher house price – depends on at least two things:

1. the buyers' expectations about energy savings for heating per sq. m. living space in the house
2. the buyers' valuation of savings in the future compared to savings (higher price) today.

Figure 3 to the left illustrates the influence of these two components. First, for each house, potential buyers have an idea about their *expected energy savings*. That is, buyers knows the energy label of the house, indicating the expected energy consumption for heating for a standard family (kWh per sq. m). They also know the energy source (district heating, oil etc.), the current energy price of that energy source and they are able to form expectations about future energy prices. Hence, for each house, potential buyers have an idea about their savings or dissavings by living in (buying) this house, as compared to other similar houses.

[5] In this framework, we can easily allow for depreciation and limited investment horizon, e.g. by assuming that energy standards only last and has a value for buyers for a certain period.
[6] By analysing the simple effect of the energy labels A-F on house prices, we find the effect of energy efficiency given average energy prices.

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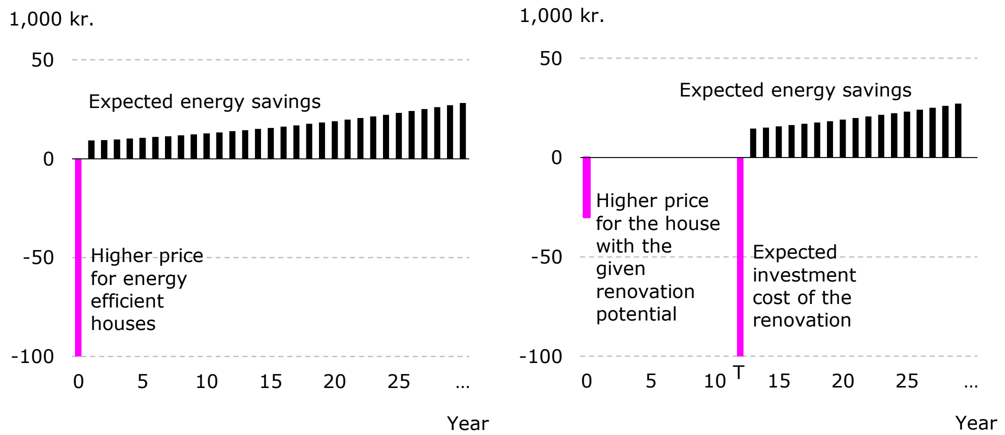
Figure 3 The problems faced by a rational housing buyer



Note: The figures are illustrative and the numbers are just examples. The figure to the left illustrates the higher price (costs) and expected savings when buying a high compared to a low energy efficient house. The figure to the right illustrates the higher price (cost) and expected investment costs and savings of renovation when buying a low energy efficient house with clear renovation potentials compared to a low energy efficient house without renovation potentials.

Source: Copenhagen Economics

Secondly, the question is how much more or less buyers are willing to pay today to have a given expected flow of savings or dissaving on their future energy bills. In Figure 3 to the left, this is shown as the relation between the *Expected energy savings* and the *Higher price for energy efficient houses*. This is a general question of peoples' valuation of future compared to current savings, typically measured by the *subjective discount rate*. Knowing buyers' subjective discount rate we can calculate the current value of a stream of future energy savings. Hence, we can calculate how energy standards should affect current house prices (see Box 1 for details).

From this framework, we are able to form simple hypotheses about buyers' willingness to pay for energy efficiency and energy savings, given standard assumptions about the subjective discount rate and current and future expected energy prices (see the hypothesis calculations in section 2.3).

The value of option to renovate

Homeowners typically have an option to renovate and thereby increase the energy standard of their house. This may have a large effect on the pricing of current energy standards.

Instead of buying a house with a high energy standard, potential buyers may have the option to buy an *all else* similar house with a low energy standard and then pay to renovate. From this perspective, the price difference between high and low energy efficient houses should never exceed the current price of renovation. In fact, a buyer may also buy a low energy efficient house, wait and see, and then renovate at a future optimal point in time if energy prices increase, if the price to renovate decreases, if new technologies become available etc.

From economic theory of option pricing, a buyer (owner) of a low energy efficient house also buys (owns) the option to renovate. This we can see as an insurance against increasing energy prices. For a rational buyer, this option has a price that we can quantify, as illustrated to the right in Figure 3. From expectations about future energy prices and renovation costs, a potential buyer form expectations about when it will be optimal to renovate (illustrated as time *T* in the figure). This optimal time to renovate we can calculate, and we can calculate the current value of the potential net savings the renovation gives rise to (the capitalised *expected energy savings*). Taking account of the *expected investment cost of the renovation,* we can calculate the value of the option today. This should amount to the *higher price for the house with the given renovation potential*, see mathematical details in Box 2.

The option to renovate may be important to incorporate in our hypothesis calculations and statistical models. The expected hypothetical effects are calculated in Section 2.3.

The effects of a higher expected selling price
When buyers pay a higher price for a high energy efficient house, or if they pay to renovate, they also expect to get a higher price when they sell. This may or may not affect their willingness to pay for energy efficiency and renovation today. On the one hand, if house prices today “fairly” incorporate energy efficiency they should also do so in the future. Hereby, it should not matter to buyers how long time they expect to live in a house – whether they live in the house to benefit from the energy savings themselves or sell the house and receive the higher selling price. On the other hand, if current house prices do not fully incorporate energy efficiency, buyers’ expected period of ownership matters for their willingness to pay and willingness to renovate. The latter scenario is critical, as it involves a social non-optimal situation where entrepreneurs and existing homeowners have an – seen overall – irrational low incentive to build and renovate houses to have a high energy standard.

Box 2 Mathematical expressions of the value of the option to renovate

Non-energy-efficient houses can be renovated, and the option to renovate has a value. Allowing for this in (1) in Box 1, the relative price of and energy-efficient house (compared to a non-energy-efficient) becomes:

$$dP_t^{ee} = \frac{1}{\rho - g} ES_t - OV_t^{er}, \quad (2) \quad (3)$$

where OV_t^{er} is the value of the option to renovate a non-energy-efficient house today or in the future. If it is optimal to energy renovate today we will have; $OV_t^{er} = V_t^{ee} - I_t$, where I_t is the renovation costs, V_t^{ee} is given from (1) in Box 1 and we get; $dP_t^{eb} = I_t$. In this case, as expected, the price difference between an energy efficient and non-energy efficient house is equal to the renovation costs. In all cases where it is optimal wait and renovate at a future point in time the price difference will be larger.

Given that energy efficiency can be seen as a discrete (0-1) variable, and given constant renovation costs, subjective discount rates and growth in energy prices (without uncertainty), the expected value of the renovation option can be written as:[7]

$$OV_t^{er} = (V_t^{ee} \cdot e^{gT} - I)e^{-\rho T}, \quad (4)$$

where T is the optimal time to renovate (seen from today), and $V_t^{ee} \cdot e^{gT} - I$ is the value minus cost of energy renovation at time T. V_t^{ee} is the time t value of the stream of energy savings from the renovation, as can be calculated from (1). The optimal time to renovate (T) can be found by optimization:

$$\frac{dOV_t^{er}}{dT} = 0 \;\Rightarrow\; T = max\left\{0,\ \frac{1}{g} log\left[\frac{\rho}{\rho - g}\frac{I}{V_t^{ee}}\right]\right\}. \quad (5)$$

We can find the cut-off value of energy efficiency (V_t^*), where it is optimal to invest/renovate today if $V_t^{ee} \geq V_t^*$:

$$V_t^* = \frac{\rho}{\rho - g} I > I, \quad (6)$$

and we can find the value of the option to renovate:

$$OV_t^{er} = \begin{cases} \frac{g}{\rho - g} I \left[\frac{\rho - g}{\rho}\frac{V_t^{ee}}{I}\right]^{\rho/g} & for\ V_t^{ee} \leq V_t^* \\ V_t^{ee} - I & for\ V_t^{ee} > V_t^* \end{cases} \quad (7)$$

The intuition is that if current energy savings of the renovation are much higher than the cost of the investment it will be optimal to renovate today. Here, we can calculate the value of the renovation (option) using standard methods of net-present-value (NPV). On the other hand, if the savings of the renovation are quite low compared to the investment cost in next few years it will be optimal to wait and renovate later. That is even in cases where the entire NPV is positive.

Source: Copenhagen Economics

2.3 The hypothetical effects on house prices

In this section, we analyse specific hypotheses of how energy standards should affect house prices, given the view of a rational buyer as outlined above. We follow the typical

[7] We could also allow for uncertainty, whereby the option to renovate also has a value as an insurance against future unexpected growth in energy prices. However, we do not assume that people include this in their housing purchase considerations.

assumptions about preferences and expectations as stated in previous literature. Further, we assume that housing buyers have an average investment horizon of 30 years, see Box 3.

Box 3 Assumptions about buyers preferences and expectations

To calculate the theory consistent hypothetical effects of energy efficiency on house prices we have to make certain assumptions.

1) First, we assume that buyers have a subjective discount rate (nominal) of 5 % per year, meaning that savings one year from now is worth 5 % less than savings today. There are two reasons for this assumption. First, 5 % is quite typical assumption in the literature, e.g. it is similar to the assumption in SBi (2013b). Secondly, we can look at housing owners cost of capital, i.e. how much extra they have to pay per year to finance a house of higher energy standard, allowing them to save money on their future energy bills. Most relevant, we consider housing owners average interest rates on housing finance from 2006 to 2014, which is exactly 5 % according to Nationalbanken's interest rate statistics for banks and mortgage banks.
2) Further, we assume that nominal price on district heating is expected to increase by 2,30 % a year, while prices on natural gas and oil are expected to increase by 2,60 % a year. These we have taken from Energinet.dk (2014) assuming an average inflation of 2 %.
3) In the end, we have to assume some average investment horizon of housing buyers, which naturally depends on the depreciation rate of houses and energy standards. However, these factors are very hard to quantify and may vary a lot from buyer to buyer and from house to house. Therefore, we will roughly assume that housing buyers have an investments horizon of 30 years.

Source: Copenhagen Economics and SBi (2013b) and Energinet.dk (2014)

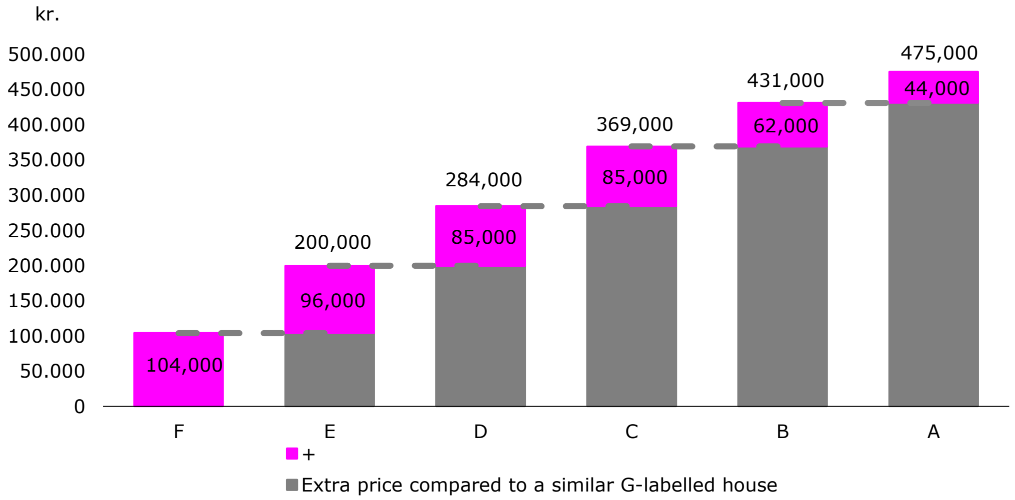
Average pricing of energy standards

First, we will consider average energy prices and current energy standard, i.e. ignore the option to renovate. For a 100 sq. m. house, we earlier found an average yearly energy savings of having a C-labelled compared to a D-labelled house of approximately 4,100 kr. Over 30 year this add up to 122,000 kr., and using (1) we find that it capitalize into a willingness to pay of 85,000 kr., see Figure 4. For a 100 sq. m. house, our calculations generally show that the willingness to pay increases by 149,000 kr. for every 10 MWh in yearly energy savings.

However, homeowners often have an option to renovate and thereby change the energy standard of their house. This can have important implications for the willingness to pay related to current energy standards. To account for this, we consider the renovation suggestions provided by energy consultants when assessing house energy labels. That is, the investment costs and energy savings related to obvious renovation potentials.

From the data, we find large renovation potentials for relatively low energy efficient houses, while the renovation potentials for high energy efficient houses are typically more expensive and in many cases virtually impossible. This is seen in the top three lines in Table 3. For low energy efficient houses (labels G to E), about 75 per cent of the houses have an obvious renovation option, and for more than 70 per cent of these the energy standard increase by at least one energy label. The opposite holds for high energy efficient houses (A to C). Further, as seen from the middle of the table, renovations last longer for low efficient houses, and investment cost are lower. In the bottom of the table, we have calculated the average option values and expected effects on the willingness to pay (using (7) from Box 2). Clearly, the option values and, especially, the expected price effects are much larger for low efficient houses.

Figure 4 Expected capitalized value of energy labels, compared to a G-labelled house



Note: Here we use average energy prices of 0.69 kr. per kWh, we consider a house of 100 sq. m. and each energy label refers to the average energy consumption within the threshold. All numbers a rounded to nearest hundred.

Source: Copenhagen Economics

Table 3 Investment potentials, costs and values related to options to energy renovate

	G	F	E	D	C	B	A	All
Share having an option to renovate	73%	74%	76%	75%	62%	18%	2%	71%
Investment potential (only houses with an option)								
Avg. renovation potential (kWh per sq. m.)	43	26	17	12	8	7	9	19
Share of renovations that change the energy label	95%	91%	73%	38%	9%	9%	0%	59%
Avg. life-span of renovation	40	32	27	25	24	18	27	29
Costs and values (only houses with an option)								
Avg. investment cost (kr. per kWh)	21	27	35	41	47	50	51	36
Avg. value of option (kr. per sq. m.)	655	439	279	165	100	140	151	287
Avg. expected price effect (kr. per sq. m.) (all houses)	**478**	**325**	**212**	**123**	**62**	**25**	**3**	**203**

Note: Here we consider all houses inspected by an energy consultant (2006-2014). We exclude outliers, i.e. observations where either the investment costs or renovation potentials are outside the 95 % confidence bound. The value of the option is calculated using (7). For houses without an option to renovate, the option value is set to zero.

Source: Copenhagen Economics

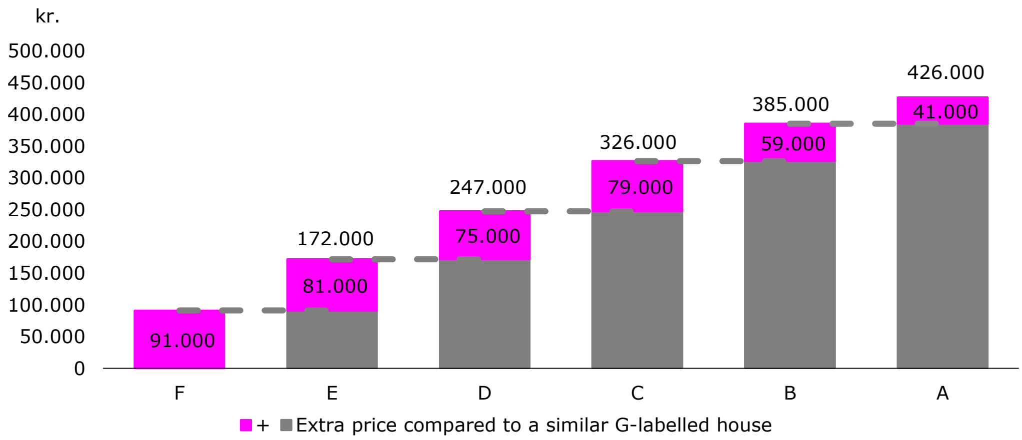
When controlling for options to renovate, the willingness to pay increases relatively more for low energy efficient houses, meaning that the additional willingness to pay for high energy efficient houses decreases. For houses of 100 sq. m., the average options to renovate is worth 6,100 kr. more for D-labelled houses compared to C-labelled houses, see Table 3 (123-62=61 kr. per sq. m.). Hereby, the price premium of a C-labelled compared to a D-labelled house decreases by 6,100 kr. from 85,000 kr. to 78,000 kr., see Figure 5. On average, the willingness to pay increases by 149,000 kr. for every 10 MWh in yearly energy savings.

From here, we form the following hypothesis:

Hypothesis 1

For a 100 sq. m. house, energy savings of 10 MWh increases the selling prices by 149,000 kr., and compared to having a G-labelled house, the energy labels A-F increases the selling prices as shown in Figure 5.

Figure 5 Expected price increase related to energy labels, compared to a G-labelled house (including option to renovat0065)



Note: Here we use average energy prices of 0,69 kr. per kWh, we consider a house of 100 sq. m. and each energy label refers to the average energy consumption within the threshold. We account for the average values of options to renovate as seen in Table 3. All numbers a rounded to nearest hundred.

Source: Copenhagen Economics

The influence of energy sources and energy prices

So far we have only considered the pricing of energy standard given average energy prices. However, the pricing of energy standards should also depend on energy prices – i.e. how much the energy savings (in kWh) give rise to in yearly saving in kr.

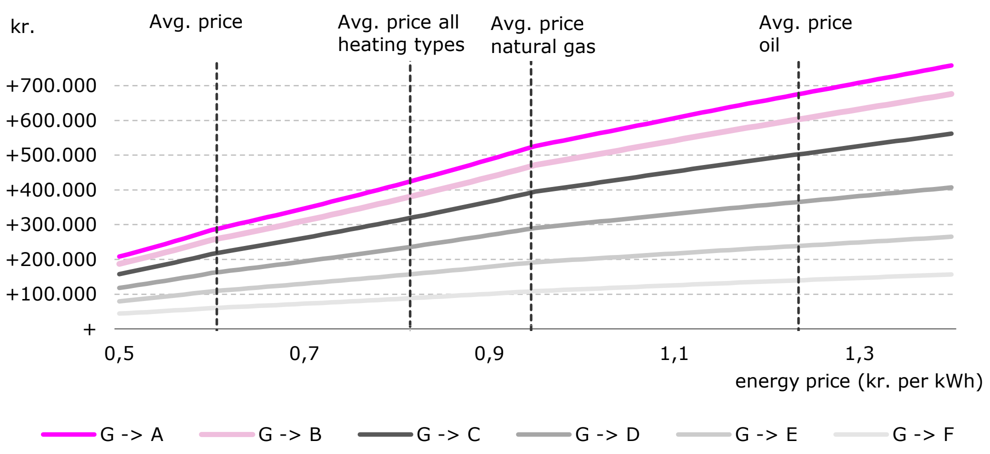
Given the large variations in energy prices and yearly energy savings as seen earlier in Figure 2 and Table 2, the timing and especially the type of heating will have large impacts on the pricing of energy standards. For example, the additional willingness to pay for C-labelled house compared to a G-labelled house is on average twice as high for oil-heated houses compared to district-heated houses. This is seen from Figure 6, showing the expected price effects of higher labels (compared to G-label) for different energy prices. Here, the price effects, of course, are highly depending on the renovation options, since this will have a much higher effect when energy prices increase. In fact, the more the energy prices increase compared to the price level during the energy inspections, the less we can trust the renovation suggestions given. More types of energy renovations will become profitable as energy prices increase. Here, we trust that the renovation suggestions related to houses of lower energy standards are most relevant for scenarios of increasing energy prices.

For a 100 sq. m. house and given the typical renovation suggestion of G, and E-labelled houses, we find that the price premium per 10 MWh in yearly energy saving increases by 216.000 kr. when the energy price increases by 1 kr. per kWh. This gives rise to our second key hypothesis to be analysed and tested in the empirical model:

Hypothesis 2

The pricing of energy standards is highly dependent on energy prices as shown in Figure 6, and for a 100 sq. m. house having yearly energy savings of 10 MWh, the willingness to pay increase by 216.000 kr. when the energy price increase by 1 kr.

Figure 6 Expected pricing of energy standards depends on the energy prices



Note: These calculations use (1) and (7) and the average investment costs, investments potentials etc. as shown in Table 3. Given the non-linearity of (7) the calculations are only approximate.

Source: Copenhagen Economics

2.4 Other important mechanisms

Naturally, the willingness to pay for higher energy standards vary for different housing buyers. Some family structures (larger families) save more for a given energy standard and people have different subjective discount rates, credit restrictions and expectations about energy prices. This leads to a question of who is the marginal buyer determining the price of a given house and what drives the pricing of energy standards (possibly away from our theoretical expected values).

Further, a large part of housing buyers may not fully understand the implication of the energy standard or it may be expensive or difficult to gain information about the energy efficiency and potential savings. A large part of the buyers may also be myopic or credit restricted, valuing current savings a lot higher than future savings. In both cases, energy standards become undervalued, and this reduces the link between energy standard and house prices.

Other factors related to energy efficiency may also affect buyers' willingness to pay. Higher energy standards can result in better indoor climate, and there may be a signal value and desire to show a care for the environment.

In the end, energy standards often correlate with other house price determinants, such as the year of construction and overall housing standard. This also has large implications when comparing sales prices and energy standards – something we will discuss when explaining our statistical models.

Copenhagen Economics

Chapter 3

Econometric models and data

In this chapter, we first explain our data, including some descriptive statistics. Thereafter, we explain our statistical methods in general, including how they complement each other. We primarily use hedonic house price models, similar to the methods used in the previous literature. However, we also use other methods and robustness checks to make sure we address the statistical challenges related to our research question. In the end, we explain these challenges and each model in further details.

3.1 Data sources and definitions

In this analysis, we use register data on all Danish private single-family houses (*parcelhuse*) sold from 2006 to 2014. Our data set originally covers 364 thousand sales of almost 300 thousand different houses.[8] However, from the outset we have excluded a number of extreme observations, as they are considered incompatible with our focus on standard houses bought by typical Danish families.[9] Further, we use different model specifications including a large number of control variables, where some observations (sales) miss information on some control variables. This limits the data set further, depending on the model specification. Our effective sample covers between 355 and 101 thousand sales and between 293 and 93 thousand different houses.

A large number of data sources have been utilized to construct our data set. From register data from Statistics Denmark, we have the sales prices, the date of sale, location and socioeconomic information on the buyer and seller. The socioeconomic information (SEI) include the disposable income, family size, years of education and education type for the family member with the highest education. From the Building and Housing register (BBR), we have data related to the housing structure, such as the size of the house, the garden and the cadastre; the number of floors and bathrooms; and whether there is a carport.

To control for the expected price given the location and time of sales, we use the quarterly sales price index from the Association of Danish Mortgage Banks (*Realkreditrådet*) for the given municipality. This index should account for all general economic and financial conditions in Denmark and the municipality at the time of sale. We also control for SKATs geographic data (GEO) on distance to the sea, forest etc., originally used to assess the property value for taxation purposes.

In the end, from the Danish Energy Agency, we have data related to the overall housing condition (HC); the year of construction, the building materials, recent renovations

[8] The raw data also include other types of houses and buildings (apartments, townhouses etc.), but energy efficiency is not comparable across these other types of houses and buildings, which is why we only focus on single-family houses.

[9] Here we have excluded observations where the selling price (3910 obs.), the size of the house (3558 obs.) or the disposable income of the buyer (3.975 obs.) are more than 3 standard deviations from the mean.

and reports on errors and omissions.[10] This also include – as the key variables in this analysis – the heating type, energy labels and obvious renovation possibilities to save energy of all houses inspected by energy consultants (given an energy label). The energy label is available for 135,000 sales. Given the heating type, we also add data on energy prices for the month of sales taken from Statistics Denmark.

3.2 Descriptive statistics

Considering all house sales in our data, Table 4 shows the number of observations and average characteristics of the houses depending on the energy label. As seen, the sample includes a large amount sales for G- to C-labelled houses, while only few sales for B-labelled houses and very few A-labelled houses. Further, we see that the average sq. m. price of houses are increasing from G to B-labelled houses, while it is very low for A-labelled houses. This could be because A-labelled houses are built recently and in more decentral locations.

Some of the most critical variables in our estimations are the number of errors and omissions (*tilstandsrapporter*), indicating the average condition of houses. As expected, the the number of errors and omissions follow the energy labels quite closely, with fewest errors and omissions for the higher labels. This indicates that the number of errors and omissions are critical control variables.

Table 4 Number of observations, average price and number of errors and omissions by energy label

Energy label	Obs.	kr. per sq. m.	Critical errors and omissions (K3)	Major errors and omissions (K2)
All	354,780	10,869	2.86	5.51
A	389	11,415	0.89	1.84
B	4,272	14,537	0.88	1.41
C	22,351	14,673	1.94	3.46
D	40,859	13,290	2.61	5.16
E	30,122	12,747	3.06	5.99
F	19,989	12,171	3.43	6.49
G	18,404	10,760	4.16	7.51
No label	218,394	9,561	2.85	5.6

Note: The tables show the distribution and average values for all house sales in our data.

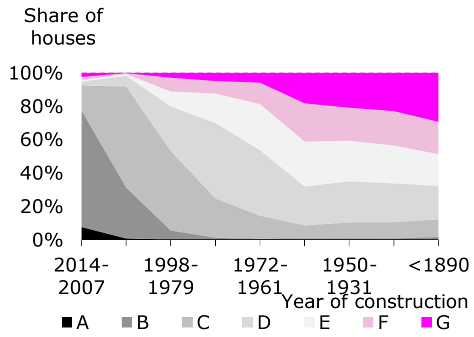
Source: Copenhagen Economics

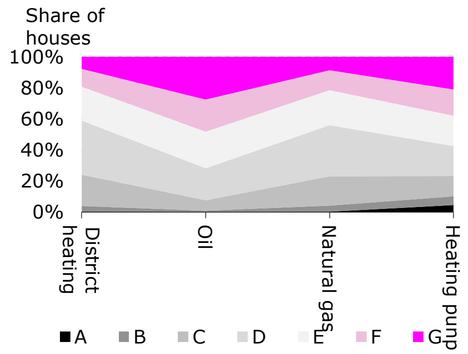
Figure 7 shows the distribution of energy labels depending on the year of construction and heating type. The year of construction also follows the energy label quite closely, with older houses typically having a lower label and *vice versa*, see the figure to the left. Especially, B and A-labelled houses are almost exclusively build after 1998 and 2007,

[10] The year of construction is actually part of the BBR register, but here we prefer to have it as part of the housing condition. The errors and omission reports (*tilstandsrapporter*) are given by consultants inspecting the house before the final sale, pointing out more or less critical errors and omissions (K1 – K3).

respectively. The distribution also seem to vary with the heating type, which has important implications for the cost of heating, see the figure to the right. This indicates that both year of construction and heating type are also important variable to control for. Finally, we analyse how the distribution of energy labels vary with the year of sale and the region, see Figure 8. Here, the distribution of houses sold with different energy labels are more or less the same in all years and in all regions.

Figure 7 Share of energy labels given the year of construction and year of sale

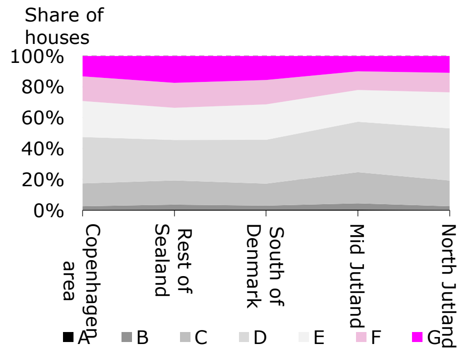


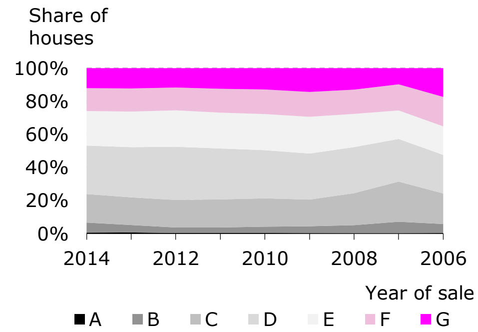


Note: This only includes the 135 thousand houses having an energy label out of our full sample of 300 thousand houses.

Source: Copenhagen Economics

Figure 8 Share of energy labels given the region and the heating type





Note: This only includes the 135 thousand houses having an energy label out of our full sample of 300 thousand houses.

Source: Copenhagen Economics

3.3 Three econometric models – an overview

We use three different types of econometric methods: a random effects (RE), a fixed effects (FE) and a matching model. All models focus on estimating the effect of energy efficiency on sales prices. There are strengths and weaknesses associated with all three methods and they do approach the overall question from slightly different perspectives using different assumptions. The models complement each other well, see Table 5, and if one method gives a different answer than the others, it may be a sign that there are problems with the assumptions related to either this or the other models.

Table 5 Strengths and weaknesses for the three methods

Model	Strengths	Weaknesses
1. Random effects (RE)	Uses the full sample and information in the data, both between and within house variation. This is efficient if the assumptions of the model are correct or if we want to know the average effect of energy efficiency within and between houses.	Problems about omitted variable bias (e.g. house maintenance). Sensitive to model specification.
2. Fixed effects (FE)	In many cases more robust to omitted variable bias.	Uses only a small part of the sample for houses sold at least twice and only fewer houses change energy efficiency between sales (inaccurate) The smaller sample also leads to sample selection/endogeneity. That is, the model only estimates the average price effect of renovated houses using within house information. Sensitive to model specification.
3. Matching	Includes test for sample selection. More robust to model specification and large outliers.	Does not use the information efficiently (inaccurate).

Source: Copenhagen Economics

For example, in method 1 (RE) we rely on both the time-series dimension (price changes between two or more sales of the same house) and the cross-sectional dimensions (price differences between the sale of different houses). Hence, the model estimates the average effect of energy efficiency on the sales prices. This may be oppose to method 2 (FE), which only relies on the time-series dimension, analysing the price change for the same house from one sale to the next given that the house is energy renovated in the meantime. Theoretically, in some scenarios the two models give the same answer. Using method 2 typically minimise the requirements for the control variables, but it may suffer from the narrow focus on only the time-series dimension and repeated sales (this is explained more carefully in Box 4).

Box 4 Understanding the random and fixed effects model

Consider a simple case where we have a large number of houses that are all bought and sold several times. For each sale of house i at time t, we have the sales price per sq. m. (P_{it}), a continuous measure of the energy efficiency or savings (ES_{it}) and a number of other price determinants/controls (PD_{it}). Buyers know the energy efficiency, and between each sale houses often change their energy efficiency. Here, we are interested in knowing the change in the sales prices (kr. per sq. m.) when we change the energy efficiency, say by one kWh per sq. m.

When using cross-sectional time-series models, we would often start by a general regression model:

$$p_{it} = \beta_1 ES_{it} + \sum_{j \in J} \beta_j PD_{i,t}^{j} + (error\ terms\ and\ constants) \qquad (1)$$

Here, we are specifically interested in β_1. As the model is shown here, it indicates that an increase in energy efficiency (ES_{it}) of one kWh per sq. m. leads us to expect, in all cases, that the sales prices per sq. m. (P_{it}) will increase by β_1. The emphasis here is on "in all cases" when we expect the same difference in P_{it} when relying on two different types of information:

1. *The between-houses information*: we observe two *all else equal* houses with a difference in their energy efficiency (ES_{it}).
2. *The within-houses information*: we observe one house sold at two different points in time, where the energy efficiency (ES_{it}) has increased between the two sales.

In the ideal case – if we could control for sufficient house, buyer, and seller characteristics – we would expect the price effect to be the same in the two cases. However, there are reasons why this does not hold in practice.

The typical explanation is that energy efficiency does not affect the price equally for all houses. In the model we try to take a hold of this by controlling for many characteristics about the house, the buyer etc. (PD_{it}), but there may still be some systematic variation in the effect of energy efficiency which is unobserved. Now, the energy efficiency of a house increases only because of energy renovation, i.e. costly investments. A rational house owner/seller will only renovate if he or she expects the sales price to increase a lot a result of it. Hence, energy efficiency may have a small effect on the sales price when we compare two all else equal houses, while it has a large effect when we consider the same house sold twice, where the owner has chosen to renovate in the meantime.

Different types of cross-sectional time-series models use different parts of the information in the data. There are three general types of panel models to use here:

1. The *between estimator*, which uses only the cross-sectional or *between-houses information* (see 1. above),
2. The *fixed effects estimator*, which uses only the time-series or *within-houses information* (see 2. above), and
3. The *random effects estimator*, which uses a weighted average of the *between-* and *within-houses* information, assuming that all unobserved housing characteristics are random and unrelated to the effect of energy efficiency.

The between and within effect estimators give the same result if all unobserved housing characteristics are random, meaning that it does not matter whether we compare two all else equal houses or the same house sold twice. It turns out, that in this case the random effects model will be the most precise model (efficient), as it relies on both the between and within house information.

However, we can test the random-effects assumption. Here we use the Hausman test to justify whether the random effects and fixed effects estimator gives the same result:

$$H_0: \qquad b_{\mathrm{RE}} = b_{\mathrm{FE}} \tag{2}$$

Thereby, the Hauseman test can be seen from two perspectives:

1. A test of whether the unobserved characteristics are truly random and unrelated to the effects of energy efficiency on prices.
2. A test of whether comparing two *all else equal* houses with different energy efficiency gives the same result (answer the same question) as when considering the same house sold twice with different energy efficiency.

Source: Copenhagen Economics

3.4 Typical statistical problems

A statistical analysis of the pricing of energy standards involves a set of typical statistical problems. Here we will discuss the three most crucial ones.

Omitted variable bias

Most obvious, energy standards often correlate with other house price determinants, such as the year of construction, the overall condition and amenity value of houses. This may increase the relationship between the sales price and energy standards, but not because of the energy standards as such. Hence, we risk overvaluing the effects of energy standards. We refer to this problem as *omitted variable bias*.

In our empirical analyses, we will minimize this possible error by controlling for a great number of details related to the overall conditions of houses, materials, general renovations as well as the building years. That said there is still a small risk that we overestimate the average effect of energy standards. Therefore, we also test the effects of energy standards using three different statistical models with different strengths and weaknesses. In the end, compared to the amenity value and other house price determinants, the pricing of energy standards should depend on energy prices. Therefore, we will also analyse how varying energy prices affect our results. If we find the expected effects – as discussed in Section 2.3 – it will be yet another verification that our models do indeed identify the causal price effects of energy standards.

Endogeneity

Further, in areas where the house prices have increased a lot over the years, homeowners typically have more equity and better economies to make renovations and the homes are newer and more luxurious. This results in yet another type of relation between house prices and energy standards, but where the causality run from higher prices to higher energy standards. We refer to this problem as *endogeneity*. In our empirical model, we will control for the overall price level of houses sold in the areas, but there is still a risk that we overestimate the effect of the energy efficiency on house prices.

Sample selection
Related to the problem of endogeneity, the energy standard and the choice of selling (whereby we observe the sales price in our data set) may be related. Homeowners who consider selling in the near future may have a higher or lower tendency to renovate depending on whether they expect it to be profitable in a sales situation. The expected price also affects their incentive to sell, whereby the chance that homeowners sell are dependent on both the energy standard and the expected sales price. We refer to this problem as *sample selection*.

In both the random effects and fixed effects models, we will make tests and regressions that are robust to this problem. Further, the matching model is in itself more robust to sample selection.

3.5 The random effects model

When complying with certain assumptions, the random effects model (RE) is the most efficient model among the standard panel models. Here we make use of both the time series information in the data by comparing different sales prices of the same house (when sold twice or more), and we use the cross-sectional information in the data by comparing sales prices of different houses.

To set up our panel data, we simply set the first sale of a given house in our sample as $t = 0$, the next sale as $t = 1$ and so on. Hereby $t=0, 1$ *etc.* only refers to the first, second etc. sale of the same house in the sample (not to the date of the sale).[11] For every sale, we control for the average selling price in the given municipality in the given quarter, as well as a number of control variables related to the house, the area and the seller (to be explained below). We assume that this controls for the date of the sale and timing between sales, meaning that there are no further correlation between the individual sales of different houses. Further, as a critical assumption in the RE model, we assume that all other factors that affect the sales prices which are not included in the model (unobserved factors) are unrelated to the energy efficiency.

From our theoretical hypothesis, we found that energy efficiency should affect the sales prices in absolute terms. For each house i at time t we focus on explaining the sales price in kr. per sq. m.; P_{it}. We generally use a hedonic price model, and the RE model can be written in the following simplified form:[12]

[11] As opposed to standard panel models, the time t in our model does not refer to any specific point in time. It only refers to the number of times the given house sold in our sample. For one house t=1 may be in 2007, while for another house t=1 may be in 2012. Therefore, we do not include time dummies; we assume that including the price index of the municipality controls for the time dimension.

[12] The hedonic price model is explained in Rosen (1974) and is used in most other related studies, see e.g. Brounen and Kok (2010), Hyland et al. (2013) and Fuerst et al. (2015).

$$P_{it} = \beta_0 \, Pi_{i,t} + f(BBR_{i,t}) + g(GEO_{i,t}) + h(SEI_{i,t}) + j(GC_{i,t}) + k(Energy_{i,t}) \qquad (8)$$
$$+\alpha + u_i + \varepsilon_{i,t},$$

where $Pi_{i,t}$ is the house price index related to the given municipality in the quarter of sale. By the terms $f(BBR_i)$, $g(GEO_{i,t})$, $h(SEI_{i,t})$ and $j(GC_{i,t})$ we control for structural factors, geographical factors, socioeconomics factors related to the housing buyers and the general condition of the houses. These price determinants are included in the model as; $\sum_{j \in J} \beta_j \, PD_{i,t}^j$, where the $PD_{i,t}^j$s are the individual price determinants for house i at time t. These are listed in Table 10 in Appendix A. α is a general constant, u_i is a random term related to house i and $\varepsilon_{i,t}$ is an error term.

The term $k(Energy_{i,t})$ include the energy standards. As in the theoretical section, we will measure energy standards in two ways:[13]

1. By the energy labels, including dummies for all energy labels A to F, leaving G as the residual: $\sum_{j=A,\ldots,F} \beta_j \, D_{i,t}^j$, where $D_{i,t}^j$ is a dummy related to energy label $j = A, \ldots, F$ for house i at time t.[14]
2. By the expected energy savings, calculated using the energy labels: $\beta_{ES,i,t} ES_{i,t}$, where $ES_{i,t}$ is the energy savings (relative to a G-labelled house) in kWh per sq. m. for house i at time t.[15]

Again, by the first way of measuring we analyse the price effect of individual labels and whether they follow the related energy savings. The second way of measuring is more broad, analysing the overall pricing of energy efficiency.

For both measures of energy standards, we do some corrections for the fact that our house price index $Pi_{i,t}$ – which is an essential control for the average price level of houses in the municipality – also include the price effect of the average energy standards of other houses in the municipality. This we explain in Box 5.

[13] We have also tried using the actual energy consumption used by previous housing owners, but this data seems very noisy. This could be due to large variations depending on the previous owner-family's composition, their attempt to save energy, as well as the weather (cold warm winter etc.).
[14] We will also include a dummy for houses without energy labels.
[15] Here, we use the average energy consumption for each energy label as shown to the right in Table 1. We will also include a dummy for houses without energy labels. The dummies equal unity if the houses have the given energy label at the given time of sale. In all other cases, the dummies equal zero.

Box 5 Method to correcting for the average energy standards

As a simplified version of our model, assume that houses can only take two energy standards – high or low. Our model explains the sales price of each house; $P_{i,t}$ from three types of price determinant;

1) the average price level of houses sold in the areas at the time; $Pi_{i,t}$,
2) the energy standard of the given house, modelled as a dummy for high energy standard houses; $D_{i,t}^{HE}$, leaving low energy standard as the residual, and
3) other price determinants; $\sum_{j=1,2,..} \beta_j \, PD_{i,t}^{j}$ (not important in this context).

The random effects model can be written as:

$$P_{it} = \beta_0 \, Pi_{i,t} + \beta_1 \, D_{i,t}^{HE} + \sum_{j=1,2,..} \beta_j \, PD_{i,t}^{j} + \alpha + u_i + \varepsilon_{i,t}, \qquad (9)$$

where the terms have the same meaning as in (8). Our focus is on β_1, which – if modelled properly – indicates the "clean" price effect of energy standard, i.e. the extra willingness to pay for houses of high energy standard as compared houses of low energy standard.

A critical problem is that this interpretation only hold if we compare with low energy efficient houses throughout the model. This is not the case from the outset, since $Pi_{i,t}$ is the price level of all houses sold in the area at the time – not only low energy efficient houses. For example, if almost all houses in one areas were high energy efficient, we would only compare with high energy efficient houses and typically find that the extra willingness to pay for high energy is close to zero.

To correct for this bias, we recognize that our model in (9) decompose the sale price of each house into a price effect of energy standards and the price effects other determinants. If this hold for house *i*, the same should hold for all houses included in the price index $Pi_{i,t}$. Hence, we can also decompose $Pi_{i,t}$ using the regression model (9): $Pi_{it} = Pi_{i.t}^{LE} + \beta_1 \sum D_{j,t}^{HE}$, where $Pi_{i.t}^{LE}$ is an underlying price index of low energy efficient houses, and $\sum D_{j,t}^{HE}$ sums up to the share of houses in the area at the time that are high energy efficient.[16]

Now, we can replace $Pi_{i,t}$ in (9) by $Pi_{i.t}^{LE}$ and get:

$$P_{it} = \beta_0 \, Pi_{i,t} + \beta_1 \left(D_{i,t}^{HE} - \sum D_{i,t}^{HE} \right) + \sum_{j=1,2,..} \beta_j \, PD_{i,t}^{j} + \alpha + u_i + \varepsilon_{i,t}, \qquad (10)$$

whereby we indirectly compare with a house price index of low energy efficient houses.

As seen, to correct for this bias, we simply have to substrate the average energy standard in the area at the given time *t* from our measure of the energy standard for each house *i*. A similar result holds in the more complicated case – the actual case – where we have more than two energy standards.

Source: Copenhagen Economics

[16] This only to the extent that $Pi_{i,t}$ is the simple average price of all houses sold in the areas at the time.

3.6 The fixed effects model

Many characteristics that affect the sales price of houses remain unchanged between two sales of the same house. This is typically also the case for energy standards, but in some cases, houses are energy renovated between two sales. Using the fixed effects model, we try to isolate the effect of changing energy standards on sales prices.

This has the great advantage that we only need to control for other conditions that are not constant over time. For example, it is no longer necessary to control for the building year, structure of the house and other factors that remain unchanged. Thus, we hope to diminish the potential problem of omitted variables as explained in section 3.4. However, it is important to mention, that this will only work if the potentially omitted variables – e.g. the overall condition of the house – are unaffected by changes in the energy standard. That may not actually be the case.

We can write the model quite similar to the RE model in (8):

$$\tilde{P}_{i,t} = \beta_0 \, \widetilde{Pi}_{i,t} + f\left(\widetilde{BBR}_{i,t}\right) + g\left(\widetilde{GEO}_{i,t}\right) + h\left(\widetilde{SEI}_{i,t}\right) + k\left(\widetilde{GC}_{i,t}\right) + k\left(\widetilde{Energy}_{i,t}\right) + \varepsilon_{i,t,}$$

where (again) i denotes the house and t denotes the time of sale. All variables are similar to the RE model, only time constants are omitted, and $\tilde{}$ indicates that we now consider deviations from the average values for the given house. For example, $\tilde{P}_{i,t}$ indicates how the sales price of a given sale differ for the average sales price the house throughout our sample. We also measure energy efficiency in the same two ways as for the RE model, controlling for the average energy standards as explained in Box 5. The interpretations are also similar to the RE.

3.7 The matching model

Both the random effects and fixed effects models may suffer from sample selection and specification problems, as well as omitted variable bias. Therefore, we do a final robustness test on our results by using a propensity score matching model. In short, this model match each house sale with other *all else similar* house sales where the house has a different energy standard, and then it compares the sales price.

Ideally, we could solve the sample selection problem by a true experiment, in which we single-handedly and randomly change the energy standard of a number of houses and set these houses for sale on the market. However, since this is not possible in practice we use a matching model to simulate such an experiment.

We will use a standard propensity score matching model. However, here we are only capable of estimating the effects of a treatment, i.e. a 0-1 event or characteristic related to a house. Therefore, we will use the matching model to determine the price effects of the higher energy standard for every two adjacent energy labels; A-B, B-C, C-D etc. For example, to estimate the effect of having A-labelled houses, we consider all sales of houses labelled either A or B and analyse how much higher the sales prices are for A-labelled houses.

The model runs in three steps. Below we consider the case of A- and B-labelled houses:

1. First, we use a probit model to estimate the probability that each house sold is A-labelled (*is treated*), based on all characteristics related to the house, housing conditions, building year, materials, the geographical area, the buyer and the seller.
2. Secondly, based on the estimated probabilities we match each house having an A-label with other B-labelled houses having an *almost equal* (as close as possible) chance of having an A-label. This matching procedure can be done in different ways, and we will use three different methods; *nearest-neighbour*, *Caliper* and *kernel* matching. To put it simple, *nearest-neighbour* matches each sale with the single most comparable sale, and compare the sales price one-to-one. With *Caliper* matching we compare one-to-many, with a certain cut-off, and with *kernel* we match one-to-all, where each other sale is weighted by how comparable it is.
3. In the end, we consider the price difference between A- and B-labelled houses. Taking the average of all price differences we find *the average treatment effect on treated,* which is our estimated price effect of increasing the energy label from B to A.

A similar procedure is used for all other two adjacent energy labels: B-C, C-D, D-E, etc.

Chapter 4
Baseline model results

In this chapter, we first present the baseline results of the three models and compare with our theoretical hypotheses. For each model we also robustness check the results in different ways. Finally, we compare the model results against each other and conclude.

4.1 The random effects model

Results when gradually adding more controls
We start by estimating the model as shown in (8), only including energy labels. In steps we add the quarterly house price index for the municipality; $Pi_{i,t}$, characteristics related to the house (BBR), geographical factors (GEO), information related to the general conditions for the house (GC); renovations, reports on errors and omissions, year of construction and information on building materials. In the end, we also add socioeconomic characteristics of the buyer (SEI). For each critical steps, we also show how much it matter to correct for the average energy label in the municipality as indicated in Box 5. Figure 9 shows the results.

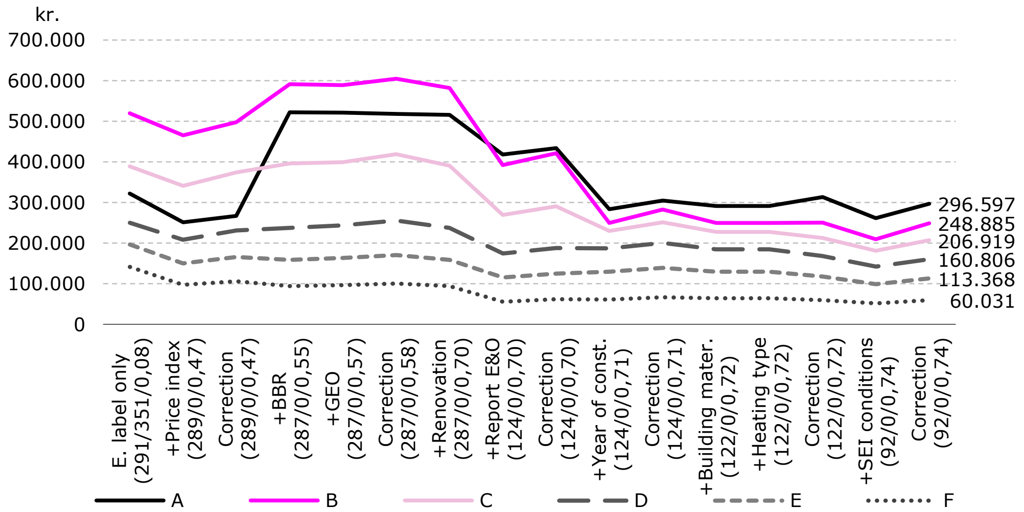
First, the results are quite sensitive to the controls included in the model. Specifically, the model indicates a much larger effect of energy standards on prices when we do not control for variables related to the condition of the house; other types of renovations, reports on errors and omissions as well as building year. This indicates, as expected, that energy standards are highly correlated with the general condition of houses, and if we do not control for these factors we will overestimate the effect of the energy standards.

After controlling for variables related to the conditions of houses, we see surprisingly small changes in the estimates when controlling for building materials and socioeconomic characteristics. However, we generally find that controlling for the average energy label in the municipality (the *corrections*) increases the price effect of all energy labels, especially for the high efficiency labels A, B and C, which are much higher than the average energy standards in the municipalities.

A similar tendency is seen from the explanatory power of the model, which increase from 0.57 to 0.70 (R^2 = 0,70) when we add information on errors and omissions. Thereafter, it only increase slightly to about 0.74 per cent when we add the additional controls. In other words, we are able to explain nearly 75 per cent of the variation in the sales prices, which is quite high given that we model non-log transformed variables.

Copenhagen Economics

Figure 9 RE model estimates of price effects of energy labels, when step-wise increasing the number of controls

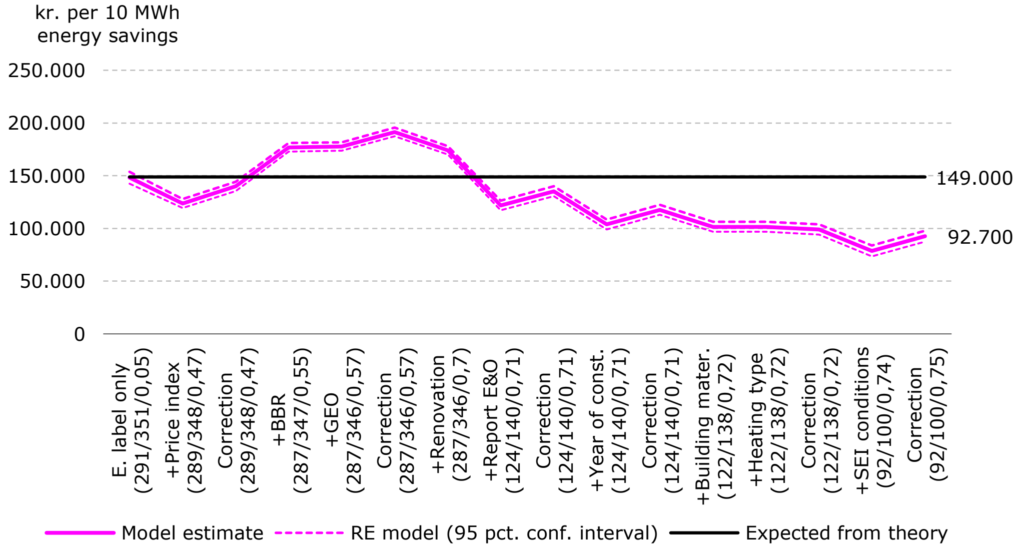


Note: The results relates to a 100 sq. m. house and all effects are measured relative a G-labelled house. The numbers in the parentheses indicate (sales×1000 / house IDs ×1000 / R^2). In the "corrections" we correct for the average energy label in the municipality as indicated in Box 5.

Source: Copenhagen Economics

Figure 10 shows the results related to our simpler measure of energy standards; the expected energy savings relative to a G-labelled house, measured in kWh per sq. m. This estimate is simpler, less detailed, but at the same time, it uses data from all houses, which makes it more precise. The figure shows more or less the same tendencies as found in Figure 9, namely that controlling for reports on errors and omission as well as the building year is very important, and it decreases the effect of energy standards significantly. In addition, we see that the overall effects of energy standards are highly significant, no matter the number of controls.

Figure 10 RE model estimate of effect of expected energy consumption, when slowly increasing the number of controls



Note: The results relates to a 100 sq. m. house and all effects are measured relative a G-labelled house. The numbers in the parentheses indicate (sales×1000 / house IDs ×1000 / R^2. In the "corrections" we correct for the average energy label in the municipality as indicated in Box 5.

Source: Copenhagen Economics

Final model estimates and comparisons with theory

When analysing the final model estimates in details, we find that the energy labels all have highly significant effects on sales prices, see Figure 11. For example, for a 100 sq. m. house, the figure shows that the expected price of a C-labelled house is 207,000 kr. higher than an *all else similar* G-labelled house, and almost 46,000 kr. higher than a D-labelled house. From the standard errors (reported below the estimates), we see that the precision of the estimates are quite high but decreases for higher energy standards. For a 100 sq. m. C-labelled house, the model precision indicates that the price effect (relative to a G-labelled house) lies between 195,000 and 218,500 kr.[17]

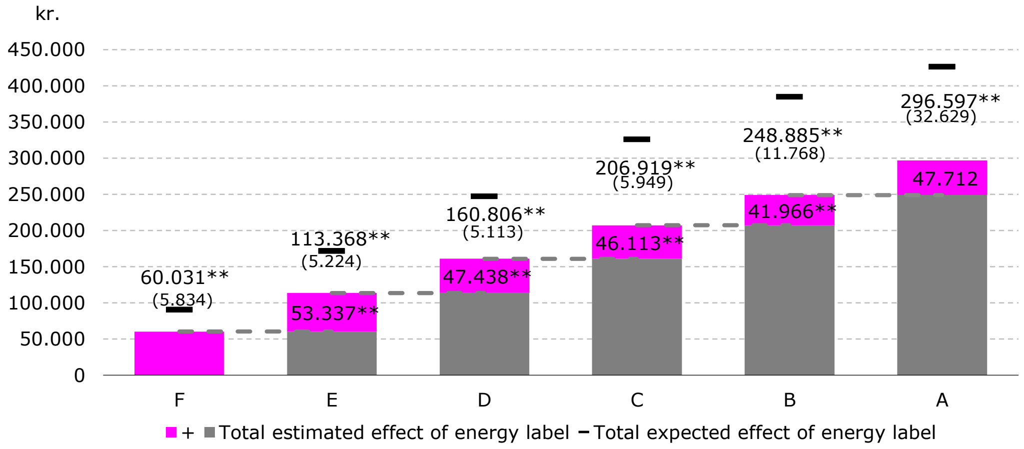
At the individual steps, we also find significant additional effects of all energy labels except for the effect of going from a B-labelled to an A-labelled house. The latter results may be because our data set includes very few A-labelled houses, or because the difference in energy consumption between A and B-labelled houses is relatively low.

When we compare the model estimates to our theoretical hypotheses, the price effects are consistently about 35 per cent below our expectations. Here, we compare with the theoretical hypothesis from Section 2.3, which are also shown in Figure 11. In our example with C-labelled houses, we estimate a prices effect (relative to a G-labelled house) of 207,000 kr., which is 34 per cent below the expected effect of 326,000 kr.

[17] This is calculated as the estimate ± 1,96 standard errors, i.e. 213.000 ± 1,96*6.125.

That said, when we consider the relative effects of each step up in energy label, the price effects are largest for the lower labels, in line with the energy savings related to the individual labels. Here, A-labelled houses is an exception, since this estimate is relatively imprecise. Importantly, if the price effects of each energy label follow the related energy savings, we lose no information by measuring energy standards in the more simple way (kWh energy savings per sq. m.) as done in Figure 10.

Figure 11 RE model estimates of price increase related to energy labels



Note: The results relate to a house of 100 sq. m. All effects are measured relative to a G-labelled house. The numbers in parentheses are standards errors. ** indicates that the estimate is significant on a 1 % significance level. The model uses 99.686 observations (sales) from 92.232 houses.

Source: Copenhagen Economics

For a 100 sq. m. house, our final estimate in Figure 10 indicates that prices increase by 92,700 kr. for every 10 MWh yearly energy savings (when not controlling for socioeconomic factors). As expected, this estimate is more precise than the estimates using energy labels and lies between the rage of 87,500 kr. and 97,800 kr. The point estimate is 38 per cent below our expectation of 149,000 kr.

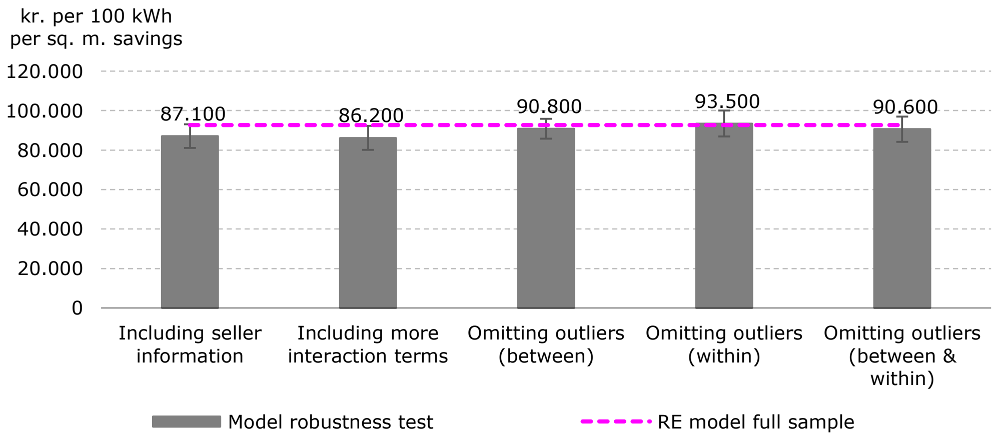
These results may generally indicate that buyers are either less informed about the actual cost of the energy labels, they are less patient or credit constraint, they have lower expectations about future energy prices than assumed, or they incorporate a higher value of the options to renovate later on. We will return to this discussion later.

Robustness tests

Being critical to our results, we do some robustness checks for large outliers, sample selection, and misspecifications in the functional form. Here, we only use the more simple measure of energy standards.[18] Our results are generally very robust, see Figure 12. Only the test for sample selection indicate that the actual effect may be a bit higher than what the main model suggest.

[18] For the test for large outliers we leave out the 10 % of observations with the highest Cook's distance (both within and between, see Box 4). We test the function form by including also seller information and additional interaction terms.

Figure 12 Robustness check of the RE results



Note: The error-bars (the I's) indicate the uncertainty of the estimates given by ±1,96 standard errors. This is for a 100 sq. m. house, and the energy savings are compared to a G-labelled house. The between and within outliers refer to way the outliers are identified, see Box 4.

Source: Copenhagen Economics

As our results indicate a critical importance of the building year and the number of errors and omission, we have also done some heterogeneity tests to see if energy standards are more important depending on these characteristics. Here, we find that energy standards have a slightly lower effect for newer houses, while the number of errors and omissions do not seem to matter, see Figure 23 and Figure 24 in Appendix B.

We conclude that the RE model results are quite robust, indicating that for a 100 sq. m. house energy standards have a price effect between 80,000 and 100,000 kr. per 10 MWh yearly energy savings.[19] This is between 46 and 33 per cent below our expectation of 149,000 kr. per 10 MWh yearly energy savings.

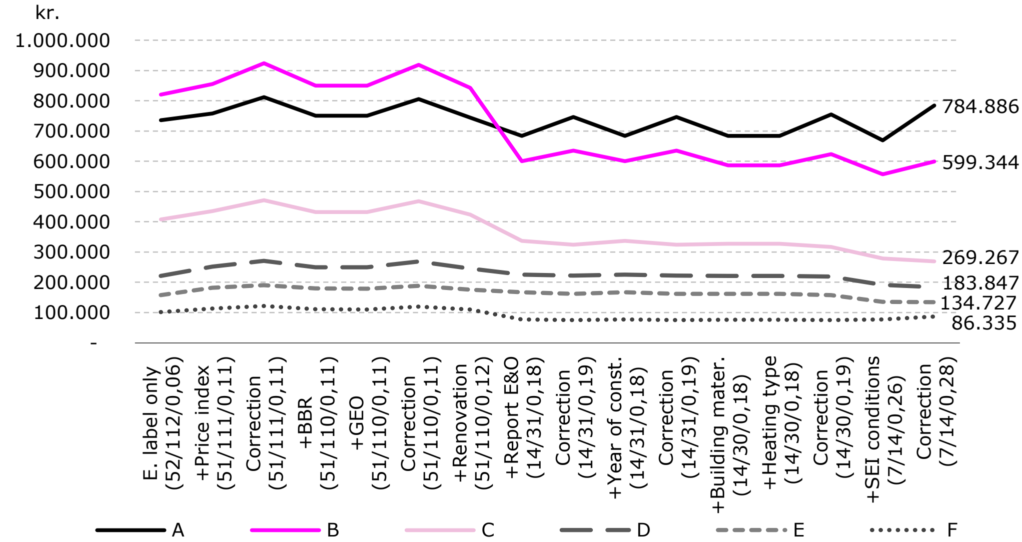
4.2 The fixed effects model

Results when gradually adding more controls

As for the RE model, Figure 13 shows the FE model results when we start with the most simple model and gradually add model controls. Here, we find even bigger changes in the results when controlling for reports on errors and omissions as well as the average energy label in the municipality. The building year matter less than in the RE model, and socioeconomic factors do not change the results much either. Generally, the explanatory power of the FE model is much lower, but here we also explain price differences and not price levels.

[19] These are the highest and lowest values in the confidence intervals, i.e. estimate ± 1.96 standard error.

Figure 13 The simple effect of energy labels in the FE model when slowly increasing the number of controls

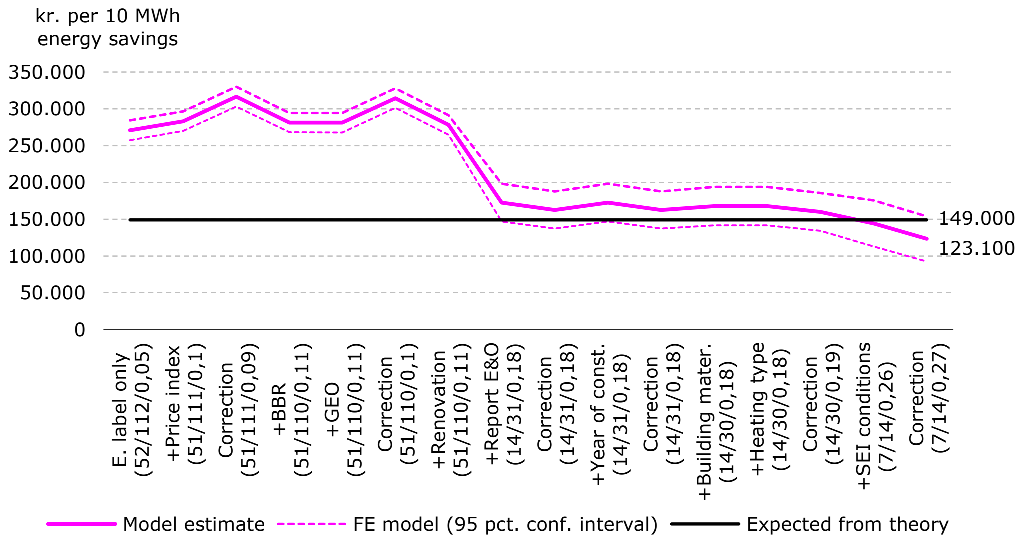


Note: The results relates to a 100 sq. m. house and all effects are measured relative a G-labelled house. The numbers in the parentheses indicate (sales×1000 / house IDs ×1000 / R^2). In the "corrections" we correct for the average energy label in the municipality as indicated in Box 5.

Source: Copenhagen Economics

Similar to the RE model we also estimate the model replacing the energy labels with the expected energy savings for a 100 sq. m. house in MWh compared to a G-labelled house. From here, we get the same impression, that the control variables are even more important in the FE model, see Figure 14.

Figure 14 Simple effect of expected energy consumption in the FE model when slowly increasing the number of controls



Note: The results relate to the relative sales price of a 100 sq. m. house. Energy efficiency is measured in MWh energy savings compared to a G-labelled house. The numbers in the parentheses indicate (obs.×1000 / IDs ×1000 / R^2). In the "corrections" we correct for the average energy label in the municipality as indicated in Box 5.

Source: Copenhagen Economics

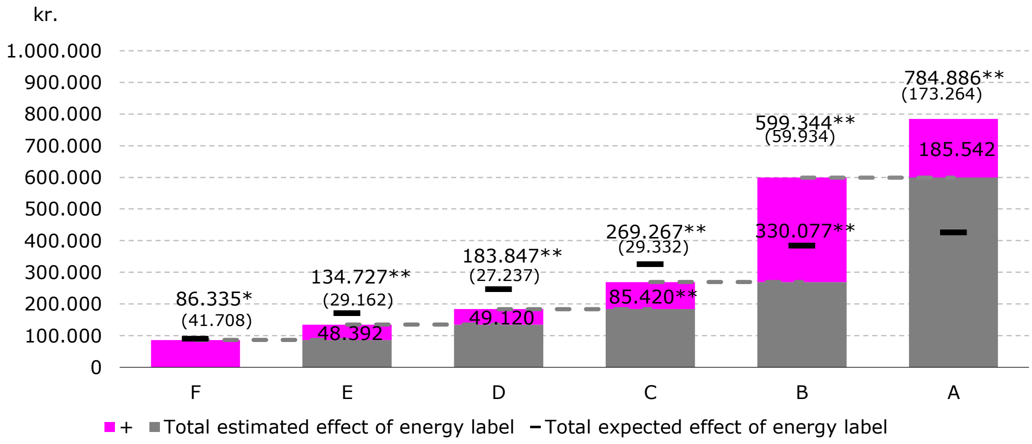
Final model estimate and comparison with theory

Further, when considering the final model estimate, the estimates are somewhat higher compared to the RE model, but the precision is also much lower in general, see Figure 15. This is especially the case for the higher labels. For example, for 100 sq. m. B-labelled houses we find a price effect of about 699,000 kr. compared to a similar G-labelled house. The precision of the estimate (the standard error) indicates that the actual price effect lies between 482,000 kr. and 717,000 kr. For A-labelled houses, the precision is even lower. The lower precision of the FE model also occur when comparing the error bands in Figure 14 and Figure 10.

For all the lower labels (F to C) the point estimates of the FE results are only slightly higher than the RE model estimates and, hence, slightly more in line with our expectations. For the energy labels A and B, the model suggests a higher price effect, but these estimates are also very imprecise. In Figure 14, when we include all controls, the theoretical expected effect is also within the error bands, indicating that we cannot reject that energy standards affect prices in line with the theory. However, we suspect this result to be driven by the high uncertainty for the higher labels A and B.

The effects of the individual labels do not follow the related energy savings as they do for the RE results. We suspect that the higher effects at the higher labels are due to omitted variables or sample selection, e.g. that changes in energy standards happen as part of a total refurbishments.

Figure 15 FE model estimates of price increase related to energy labels



Note: The results relate to a house of 100 sq. m. All effects are measured relative to a G-labelled house. The numbers in parentheses are standards errors. ** indicates that the estimate is significant on a 1 % significance level. The model uses 14.459 observations from 7.005 houses.

Source: Copenhagen Economics

Robustness test and comparing the model results

Also for the FE model, we test the model estimate for effects of large outliers, sample selection and functional form misspecifications, see Figure 16. As seen, the results are quite sensitive to the different types of misspecifications. Especially leaving out large outliers decreases the estimate significantly, and the estimate then falls below the RE model estimates. This indicates that the relatively large effects found in the FE model is due to large outliers.

We also test the heterogeneity across the building year, showing a large effect for houses build between 1930 and 1960, while no significant effect for houses build after 1973, see Figure 23 in Appendix B. This is an indication that the FE results are driven by general renovations of older buildings. Further, we also find that the effects are much smaller for houses with fewer errors and omissions in the second sale compared to the first, see Figure 24 in Appendix B. This may indicate that our results are driven by houses that have been under bigger renovation initiatives.

In the final model specifications, we also test whether the RE and FE results are significantly different using the Hausman test. This is done both for the models where energy standards are measured by energy labels and when they are measured by expected energy consumption (kWh per sq. m.). As expected, both tests resoundingly reject with a p-value of 0.000. This indicates that the results of the two models are significantly different. The Hausman test is explained in the bottom of Box 4, and compare to the two possible interpretations, we see this as an indication that the RE and FE models does not give answer to the same question in this case.

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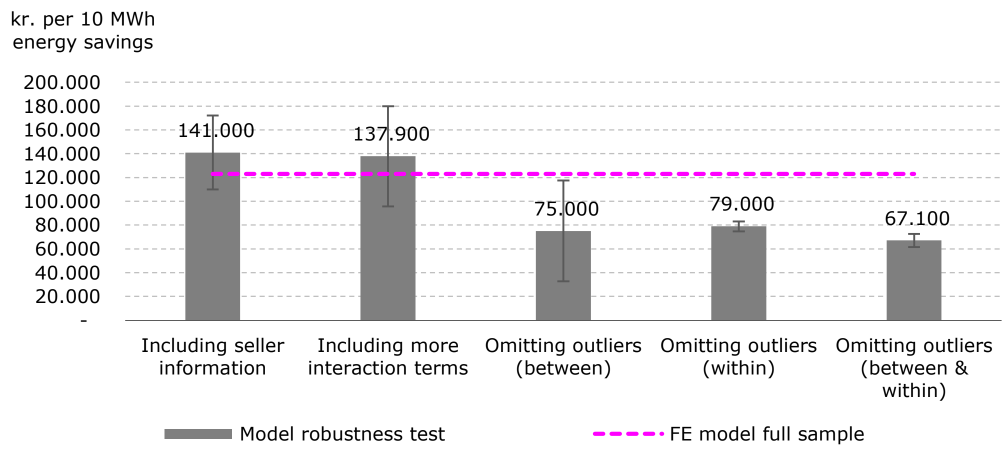
Overall, the robustness test suggests that the FE model suffer from large problems of outliers and possibly omitted variables. These problems seem to more critical for the FE model, since the model only uses repeated sales, it relies on very few observations where the energy standard change, and the energy standard is typically changed in combination with bigger renovation initiatives. The results of the FE model can be summarised by a span in the effects of energy standards between 62,400 and 183,100 kr. per MWh.[20] This does not reject that the more precise RE model estimates can be true.

Figure 16 Robustness test on the FE results



Note: The error-bars (the I's) indicate the uncertainty of the estimates given by ±1,96 standard errors. This is for a 100 sq. m. house, and the energy savings are compared to a G-labelled house. The between and within outliers refer to way the outliers are identified, see Box 4.

Source: Copenhagen Economics

4.3 The matching model

To do a final robustness test on our results, we also analyse the effects of energy standards on house prices using propensity score matching. We have tried using this method directly on the actual sales price. However, in this case the model will compare houses in different areas sold at different points in time as long as they have the same change of having a given energy standard. Hence, the results of the model will be very messy when not controlling for other factors. Therefore, we do a two-step procedure. In the first step, we use the random effects model to clean the house prices for factors not related or correlated with the energy efficiency; the house price index for the municipality, the housing structure (BBR), geographical factors (GEO) and renovations. As building year, reports on errors and omissions and building materials are found to correlate with energy efficiency we do not control for these factors. Hereby the RE model explains about 56 per cent of the variations in house prices.[21] From here we calculate a

[20] These are given from the largest confidence intervals, i.e. estimate ± 1.96 standard errors.

[21] We have also tried to "clean" the prices more or less by including more or less control variables in the RE model. When we clean for less the results do not change, the only become noisier. When we include more controls in the RE model we leave less price variation to be explained in the matching model and possibly related to the energy labels.

house price index in excess of the RE model predictions (*actual sales price – RE model predicted sales price*).

In the second step, we use the matching model to determine the effects of the energy labels on the cleaned house prices. This is done for every two adjacent energy labels – A-B, B-C, C-D etc. – as explained in Section 3.7. Since this is a robustness test, we only show the final model estimates.

Generally, our results using matching indicate somewhat smaller effects of energy standards compared to the main RE and FE results. For example, when we use kernel matching, we find a price premium for a 100 sq. m. C-labelled house of 168,700 kr. compared to an all else similar G-labelled house, see Figure 17. Here, the RE and FE results indicated a premium on 207,000 kr. and 269,900 kr., respectively. Similar differences are found for the other labels and when we use other types of matching principles; *nearest-neighbour* and *Caliper (0,001)*, see Table 11 in Appendix B.3. On average, the three types of matching models indicate that prices increase by 74,000 kr. per 100 kWh in yearly energy savings per sq. m., where the RE and FE models indicated a minimum of 80,000 kr. and 67,100 kr. in the robustness tests.

The matching model is more robust to sample selection problems, when homeowners' sales choices correlate with either the energy label or the expected sales price. As such, this indicates that the FE and RE models may be influenced by such problems, as we also found in the robustness test of the FE model.

That said, the results of the matching model are quite in line with the RE model shown in Figure 11. In fact, given the high uncertainty of the model it does not reject that the RE model results are true.

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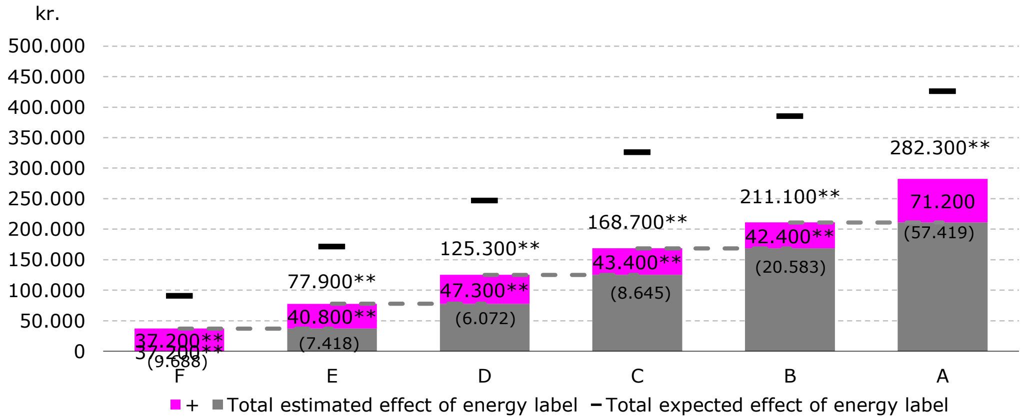
Figure 17 Matching model estimates of price increase related to energy labels, compared to G-label



Note: We use the Kernel matching principle. This is for a 100 sq. m. house, and the effects are relative to a G-labelled house.

Source: Copenhagen Economics

4.4 Conclusion on the baseline models

We conclude that energy standards have positive significant effects on house prices, no matter which model we choose and how many control variables we include etc. That said, there are some significant differences between the results of the three models, and some of them seem more affected by certain types of statistical problems.

Normally, when there are large difference in the results of RE and FE models it indicates that there are important unobserved characteristics that we do not control for in the RE model. This suggests the use of the FE model. However, we *do* control for many detailed housing specific characteristics. Further, the "important unobserved characteristics" (e.g. more details on the general condition of the house etc.) probably also change when the energy standard of houses change. If this is the case, the unobserved effects are not constant and independent and, hence, the FE model will not solve the problem of omitted variable bias.

Instead, the robustness test and heterogeneity test of the models indicate that the FE model – as is a possible weakness of the FE model – uses a significantly smaller sample and tend to suffer from sample selection bias and large outliers. Once we control for these issues the results of the FE model drops significantly and indicate a price effect below the RE models estimates (rather on the contrary) .

The matching model indicates that the RE model results may be a bit too high, but not much. In addition, it does not reject the RE model results. From here, we tend to conclude that the RE model results are quite robust to all types of statistical problems, among the three models it is much more precise and the relative effects of the individual labels are in line with our theoretical expectations.

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Chapter 5
Model extensions

In this section, we extend the models from the previous section in different directions, in order to analyse how the price effect of energy standards is affected by the theoretical important factors discussed in Section 2.3. On the one hand, this is interesting in itself, and we can see the baseline results from the previous section as average effects, while the effects in specific sales situations should depend on the energy price at the time, the option to renovate and possibly the timing, region and type of buyer. Hereby, we gain information on why the effect deviates from theory.

On the other hand, these extensions are important for our statistical identification in the models. Energy prices may serve as a type of instrument. In previous section we found that energy standards are highly correlated with the general condition of houses, and since the general condition also affects the house price, we may over- or underestimate the effect of energy standards on house prices. However, in contrast to the general condition of a house, the pricing of energy standards should be heavily dependent on energy prices, as found in Section 2.3. Hence, finding that the pricing of energy standard varies with energy prices, we can be more certain that the effects are in fact driven by energy standards and not just correlations with the general condition of houses, renovations, building year etc.

Given the conclusion from the last section, these extensions will only be done for the RE model, and to some extent the matching model. More so, we will primarily measure energy standards in the more simple way, namely as the expected energy savings for a 100 sq. m. house compared to a G-labelled house.

5.1 The influence of energy prices and timing

To analyse the effect of energy prices we add to the RE model in (8) a couple of variables: the energy prices for the heating type at the time of sale (kr. per kWh); $EP_{i,t}$, and an interaction term between the energy price and the expected energy savings per sq. m. relative to a G-labelled house; $ES * EP_{i,t}$. From here we get the RE model:

$$P_{it} = \beta_0 \, Pi_{i,t} + \beta_1 ES_{i,t} + \beta_2 EP_{i,t} + \beta_3 ES * EP_{i,t} + f\left(Controls_{i,t}\right) + \alpha + u_i + \varepsilon_{i,t}. \quad (11)$$

The interaction term measures the expected energy savings per sq. m. (kr. per sq. m.), and the related coefficient (β_3) measures to what extent the pricing of energy standards vary with the energy price.[22] Energy prices are demeaned and cleaned for any correlation with energy standards.[23]

[22] The model includes the expected energy consumption in kWh per sq., the current energy price in kr. per kWh and the interaction term kr. per sq. The coefficient in front of the latter will measure how much the pricing of energy standards in kr. kWh per sq. very when the energy prices change.

[23] If we did not do this, the average level of energy prices and correlation with the expected energy consumption would distort the results. For example, most energy efficient houses are also heated by cheaper energy sources.

When estimating the RE model in (11), the average pricing of energy standards are more or less unchanged compared to the baseline RE model, see Table 6 (compare with Figure 10). That is when energy prices are around the average of 0.69 kr. per kWh. If every price increase by 1 kr. per kWh the pricing of energy standards for a 100 sq. m. houses increase by 39,200 kr. per 10 MWh yearly energy savings. This is approximately the average difference between the price of district heating and oil, see Figure 2.

From our theoretical hypothesis calculations, we expected to find a price premium per 10 MWh yearly energy saving of 216,000 kr. when energy prices increase by 1 kr. per kWh. Hence, the dependence on energy prices is significant but way below our hypothetical expectations. This may be a result of the fact that houses with expensive energy sources have the option to change energy sources, which we have not taken into account. Further, we only consider the primary energy sources. For example, many electrical heated houses often have an alternative energy source (perhaps even solar panels), which would bias the results significantly.

Table 6 Estimation results when controlling for energy prices

Variable	Coefficient estimate
Expected energy savings in MWh ($ES_{i,t}$ related to β_1)	96,400***
Energy price at the time of sale in kr. per kWh ($EP_{i,t}$ related to β_2)	433***
Interaction term: Expected energy savings in kr. per sq. m. ($ES * EP_{i,t}$ related to β_3)	39,200***

Note: The energy savings are relative to a G-labelled house. *** indicates that the estimates are significant on a 1 % significance level. This coefficient relate to a 100 sq. m. house.

Source: Copenhagen Economics

There is a risk that these effects are just results of a tendency, where people pay more and more attention to the energy labels over time. This we analyse later. Maybe this tendency has resulted in increasing effects of energy standards over time, and it is just a coincidence that energy prices also have risen, leading us to find the results as shown in Table 6. To test whether this is the case, Figure 18 shows the model where we have allowed for interaction terms between the heating types and the energy standards. That is, instead of the actual energy prices at the time of sale, we rely on the average energy prices for each house over the sample period.

As seen, energy standards has a significantly higher price effect on houses heated by the more expensive energy sources (oil and natural gas) and a smaller effect on houses heated by distinct heating and to some extent heat pumps. The sizes of the effect do not seem to relate exactly to the actual average energy prices. For example, we should expect a larger difference between the effects on oil-heated and natural gas-heated houses. Still, the results seem to confirm, that the correlation between energy prices and the prices of energy standards are not just a time-series phenomena.

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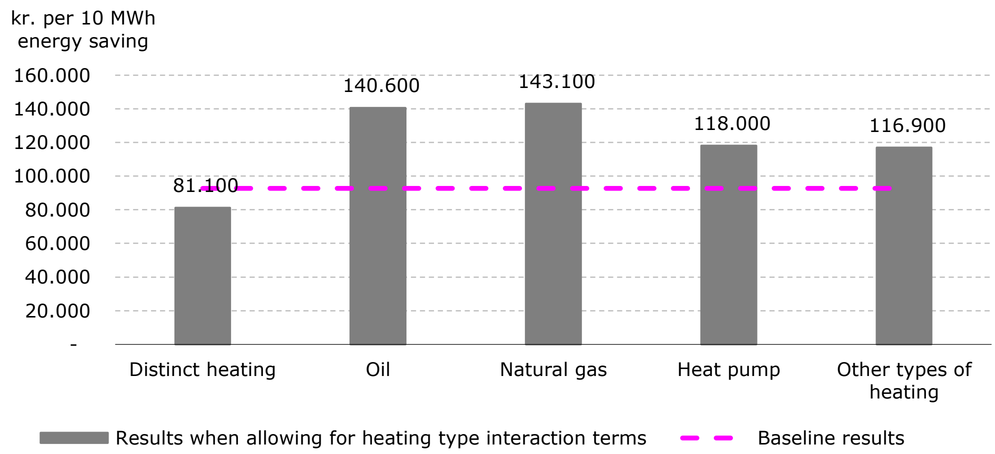
Figure 18 Pricing of energy standards and type of heating



Note: Here we have excluded houses heated by electricity. Other types of heating include firewood, straw, coal and coke. This is for a 100 sq. m. house, and the energy savings are compared to a G-labelled house.

Source: Copenhagen Economics

Finally, we have analysed the effect of energy prices using the matching model. Here, we divide the sample into three equal sized sub-samples depending on the energy price:

1. Low price: All observations where the energy price is below 0.65 kr. per kWh.
2. Medium prices: All observations where the energy price is above 0.65 kr. per kWh but below 1 kr. per kWh.
3. High prices: All observations where the energy price is above 1 kr. per kWh.

For each sub-sample we run the same matching procedure as done for the entire sample in Section 4.3. Table 7 shows the results using the Kernel matching procedure – the results of the other procedures are similar but noisier. As seen, the effect of energy standards are significantly higher when the energy prices are higher.

Generally, these results indicate that energy prices have a significant importance for the effects of energy standards, as we expect. However, the effects are much lower than expected. This could partly reflect that we do not control for alternative energy sources or options to change energy source. Still, this could indicating that housing buyers may be uninformed about the implications of energy standards, relatively short sighted or credit constraint.

Table 7 Price effects of energy labels depending on energy prices, estimate by propensity score matching

	G->F	F->E	E->D	D->C	C->B	B->A	Average price per 10 MWh
Low energy prices	36,930*	15,542	33,330**	40,164**	8,080	83,717	73,516
	(2.56)	(1.43)	(3.72)	(3.18)	(0.28)	(1.08)	
Accumulated effects	36,930	52,472	85,802	125,966	134,046	217,763	
Medium energy prices	40,090	56.990**	48,859**	10,509	85,030	-	93,894
	(1.26)	(2,96)	(3.62)	(0.52)	(1.2)	(-)	
Accumulated effects	40,090	97,080	145,939	156,448	241,478	-	
High energy prices	57,371**	69,050**	66,280**	61,380**	64,887	-	133,280
	(3.89)	(5.68)	(6.32)	(3.86)	(1.48)	(-)	
Accumulated effects	57,371	126,421	192,701	254,081	318,968	-	

Note: The three energy level are: *Low*) energy prices < 0.65 kr. per kWh, *medium*) 0.65 < energy prices < 0.95 kr. per kWh, *high*) energy prices > 0.95 kr. per kWh. All A-labelled houses are in the low energy price sample and, hence, we cannot do the matching for these on other energy levels.

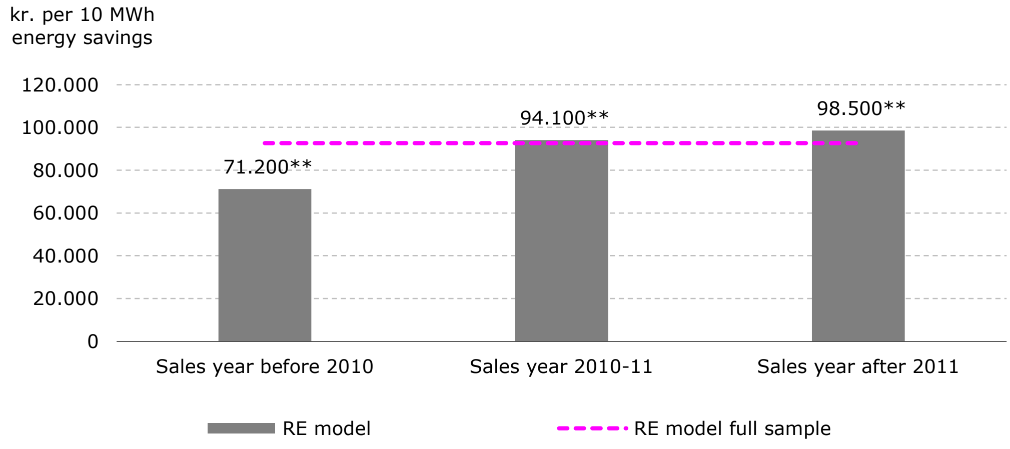
Source: Copenhagen Economics

In addition, as mentioned, there may be an increasing effect of energy standards over time, e.g. as buyers become more informed about the implication of energy standards. To analyse this, we have divided the sample into three periods (with about equal number of observations) and estimated the RE model in (8) on each sample: *i*) houses sold before 2010, *ii*) houses sold in 2010 and 2011, and *iii)* houses sold after 2011. In the latter two periods, the reporting of energy standards became mandatory.

The effects of energy standards seem to increase over time, see Figure 19. This is in line with the results found in SBI (2013). This may be because of the increasing energy prices over time and/or a general higher focus on the energy standards of houses, especially after it became mandatory to report the energy label when selling a house. The two models indicate that the pricing of energy efficiency measured in kWh per sq. m. has increased by between 8 and 12 % from 2008 to 2012 (average sales year), a period over which the average energy prices increased by a bit more than 20 %.[24]

[24] The fact that energy labelling became mandatory in 2010 may also have a selection effect, where the energy label is only reported when it affects the house price positively. Similar tendencies are discussed in both Brounen and Kok (2010), Hyland et al. (2013) and Fuerst et al. (2015). Before 2010, there it is quite possible that housing sellers only payed of an energy inspection and reported the energy label of the house if he or she expected it to have a positive effect on the sales price.

Figure 19 RE results depending on the time of sale



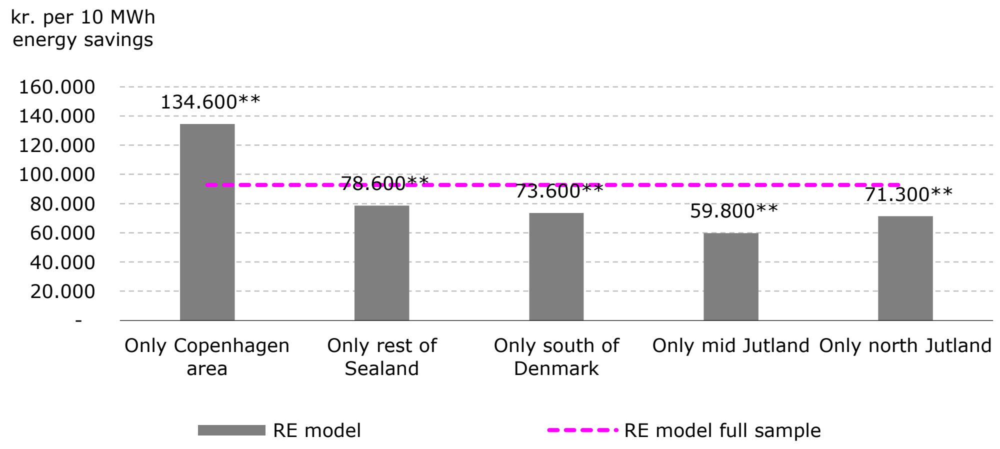
Note: This is for a 100 sq. m. house, and the energy savings are compared to a G-labelled house.

Source: Copenhagen Economics

5.2 The influence of region and type of buyer

Further, we will also analyse the heterogeneity across areas and buyer characteristics. First, we have estimated the RE model in (8) on the five regions of Denmark: the capital region, mid Jutland, north Jutland, Zealand and southern Denmark. As seen from results in Figure 20 , we generally find that the effects of energy standards are significantly higher in the capital region – almost twice as high as in other regions – lower on the rest of Zealand and lowest in the less densely populated area of Jutland.

Figure 20 RE results depending on the region

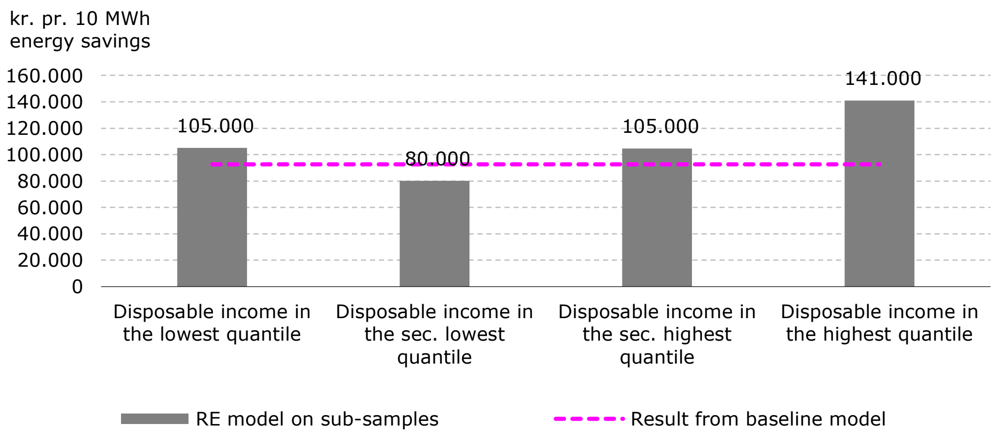


Note: This is for a 100 sq. m. house, and the energy savings are measured relative to a G-labelled house.

Source: Copenhagen Economics

Further, we have analysed the RE model in (8) on four sample, depending disposable income quantiles of the buyer. Here we find that energy standards have the highest price effects for high-income buyers which can indicate that buyers with no credit constraints have better possibilities to look beyond the larger up front cost and focus on the long term economics. The slight increase in the lowest quartile may indicate some degree of credit constrains or at least a higher subjective discount rate for low income families.

Figure 21 RE results depending on the disposable income of the buyer family

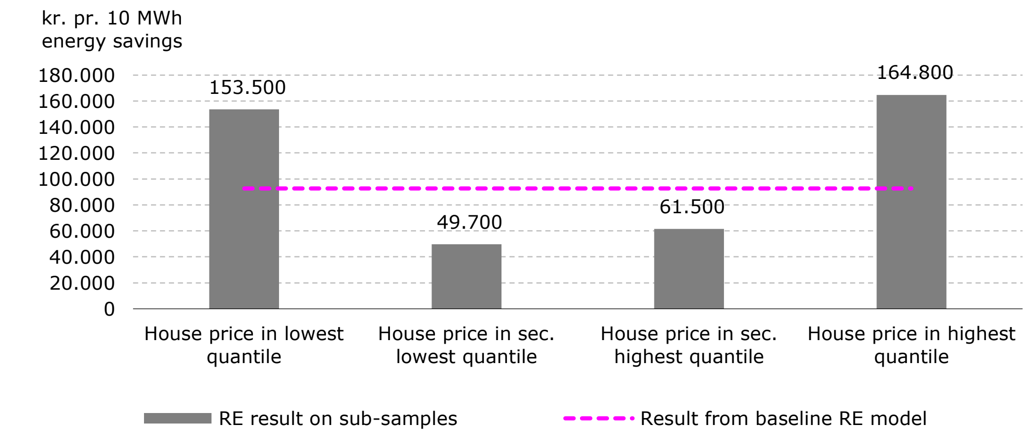


Note: This is for a 100 sq. m. house, and the energy savings are measured relative to a G-labelled house.

Source: Copenhagen Economics

Similar tendencies are found when analysing the heterogeneity across sales prices, using a similar method, see Figure 22. Here where we find the highest effects of energy standard for houses in the highest price quantile, but the effect is almost as high for houses in the lowest price quantile. The similarities between the effects found in Figure 23 and Figure 24 are not that surprising, since the wealthier families typically buy the more expensive houses. Given that the average house prices and disposable income is higher in the capital region, this also explains or related to the regional heterogeneity found above, see Figure 20.

Figure 22 RE results depending on the sales price



Note: This is for a 100 sq. m. house, and the energy savings are measured relative to a G-labelled house.

Source: Copenhagen Economics

5.3 Other characteristics

We have also analysed the influence of options to renovate, using the RE model in (8).[25] However, this does not have any significant effects on the sales price in the RE model, and the effects of energy standards does not change significantly. This could be due to a relatively low data quality on energy renovation suggestions. Another explanation could be that the option to renovate typically is higher for houses in poor conditions. Hence, the positive effect of the options may generally be offset by a lower value of the house. However, we did find a significant higher effect of energy standards for houses build between 1930 and 1960 compared to houses build before, see Figure 23 in Appendix B.2. Typically, houses build before 1930 have relatively good potentials for energy renovations, which could explain this result.

5.4 Conclusions on the model extensions

It is clear that the pricing of energy standards in specific sales situations varies depending on a range of characteristics. In line with our theoretical expectations, we found robust indications that energy prices are one important factor. This also confirms that our models do capture the effect of energy standards, and not just other omitted variables. In line with this, the effects of energy standards also seem to increase over time.

On the other hand, in contrast to theory, we find no clear effects of the options to renovate. However, this may result of a tendency that houses with obvious renovation potentials are in worse overall conditions.

[25] Here we have included the option values calculated using (7), both individually and in interaction with the energy standards.

Looking at different market segments, we found that the pricing of energy standards is higher for high-income groups, more expensive houses, and in the capital region (competed to other regions). This indicates that buyers have different constants, information available or different preferences for current vs. future savings. To understand why the pricing of energy standards deviate from the theoretical expectations of a rational buyer, this will be an obvious field for further future analyses.

Chapter 6

Comparing our results to the existing literature

Many countries have implemented housing energy standards similar to the Danish, after the passing of EU Directive on the Energy Performance of Buildings. Based on these, earlier studies have analysed the effects of energy standard on house prices in Holland, Ireland, England, Denmark and other countries. These studies use similar detailed register data and hedonic price models as done in the current analysis.

Overall, the studies find significant effects of energy standards on house prices, and the price effects seem to follow the ranking of the energy labels quite systematically. Compared to an average energy standard, very high and very low energy standards increase and decrease the sales prices by 5-10 percent, see the summarised results in Table 8. At this point, the results are quite in line with the current study.

Table 8 Results in earlier studies

Study	Country	Sample	Label Type	Trans. type	Major finding
Fuerst et al. (2015)	UK	1995-2012	A-G	Sales	Positive significant effects on sales prices and first difference of sales prices. Relative to a D-label: A/B (5 %), C (1.8 %), C (1.7 %), E (-0.7 %), F(-0.9 %) and G(-6.8 %).
Hyland et al. (2013)	Ireland	2008-2012	A-G	List-ing price	Positive significant effects on sales and rental prices. Sales prices relative to a D-label: A(9.3 %), B (5.2 %), C (1.7 %), E (0 %), F/G(-10 %)
Brounen and Kok (2010)	Nether-lands	2008-2009	A-G	Sales	Positive significant effects on sales prices. Relative to a D-label: A (10.2 %), B (5.5 %), C (2.1 %), E (-0.5%), F (-2.3 %) and G (-4.8 %).
Sbi (2013)	Den-mark	2011-2012	A-G	Sales	Positive significant effects on sales prices. Relative to a D-label: A/B (6.4 %), C (6 %), E (-6.2 %), F (-12.3 %) and G (-19.4 %).
Kok and Kahn (2012)	USA, Cali.	2007-2012	Green Label	Sales	California homes labelled with an Energy Star, LEED or GreenPoint rating sell for 9% more than compa-rable houses.

Source: Copenhagen Economics

In a study of Dutch house prices from 2008 to 2009, the authors find that, compared to a D-labelled houses, A-, B- and C-labelled houses sale at a premium of 10, 5.5, and 2 percent, respectively.[26] On the other hand, E-, F- and G-labelled houses sale at a discount of 0.5, 2.5, and 5 percent, respectively. An Irish use list prices from 2008 to 2012, finding quite similar results.[27]

[26] Brounen and Kok (2010) study 32 thousand housing transaction in the Netherlands from 2008 to 2009 where energy labelling was optional. They control for a rage of factors related to each house, including a two-step Heckman-correction for the fact that energy labelling is not mandatory.

[27] For Ireland, Hyland et al. (2013) use list prices, rather than final transaction outcomes. Their data includes almost 400 thousand properties, where 5 percent had a Building Energy Rating (BER). They also use a two-step Heckman-correction.

For the UK, a recent study uses a FE model on sales prices from 1995 to 2012 – quite similar to FE method used in this study. They find that A- and B-labelled houses sale at an average premium of 5 percent (compared to a D-label), C-labelled houses sale at a premium of 1.8 percent, and E-, F- and G-labelled houses sale at a discount of 0.7, 0.9 and 6.8 percent, respectively. The authors also find large differences depending on the type of dwelling.

A few earlier studies are using Danish houses prises and energy standards. In the most recent study, SBi (2013) analyse the absolute effect of energy labels on sq. m. prices of about 34 thousand single-family houses sold in 2011 and 2012. Compared to the current study they use a simple OLS regression and do not account for information on the quality of houses, which we found as very important control variables. Converted to percentages and relative to D-labelled houses, their results suggest that A and B-labelled houses are sold at an average premium of 6.4 percent, while C-labelled houses are sold at a premium of 6 percent, and C-, E- and F-labelled houses are sold at a discount of 6.2, 12.3 and 19.4 percent.[28]

In the US they use a somewhat different system, but several studies have also found significant effects of energy standard on house prices in the US.[29] For example, for houses sold in California from 2007 to 2012, a study finds that "high energy standard" adds a 9 percent price premium.

Most other countries and studies use somewhat unclear definitions of energy standards, without a reference to expected energy consumption. In contrast to theory, most papers also study the relative effect of energy standards and none of the studies actually discuses or compares with the theoretical expectations given rational housing buyers. Hereby, it is difficult to compare the quantitative results. Still, Table 10 shows the results of all papers, where we have converted our results in to percentages using the average prices of D-labelled house. For the other Danish our results are directly comparable, and apart from the higher labels (A and B where SBi (2013) combine the two labels into one), our results indicate a slightly lower effect of energy standards on sales prices. This is probably a result of the fact that the authors do not control for the general condition of houses, such as the number of errors and omissions.
Compared to the other studies, Irish and Dutch energy standards seem to have more or less the same effect on house prices as Danish energy standards. UK energy standards seem to have a somewhat lower effect. However, it is not possible to say whether this is because of different definitions of energy standards or other differences between the countries.

They find that, relative to a D-labelled house, A-, B- and C-labelled houses sales at a premium of 9.3, 5.2 and 1.7 percent, respectively F- and G-labelled houses sold at an average discount of 10.6 percent.

[28] In kr. per sq. m. the price premium found in SBi (2013) are, relative to a D-labelled house: A/B (+834 kr.), C (+788 kr.), E (-805 kr.), F(-1,603 kr), G(-2,527 kr.). Deloitte (2012) have done a somewhat similar study, finding much larger effect. However, here they do not control for any factors related to the house, except for the region and the heating type.

[29] Kok and Kahn (2012) analyse 1.6 million single-family houses sold in California from 2007 to 2012. Out of these, 4,321 houses were certified with an energy label. They use a hedonic price model including a large number of controls, and their results suggest that a "high energy standard" adds a 9 percent price premium. Somewhat similar are found in in a study by Margaret Walls et al. (2013) for houses built between 1995-2006 in North Carolina.

Table 9 Comparing our results with earlier studies

Energy label	Denmark	UK	Holland	Ireland	Our study
A	6.4%	5.0%	10.2%	9.3%	10.2%
B	6.4%	5.0%	5.5%	5.2%	6.6%
C	6.0%	1.8%	2.1%	1.7%	3.5%
D	0.0%	0.0%	0.0%	0.0%	0.0%
E	-6.2%	-0.7%	-0.1%	0.0%	-3.6%
F	-12.3%	-0.9%	-2.3%	-10.0%	-7.6%
G	-19.4%	-6.8%	-4.8%	-10.0%	-12.1%
Authors	Sbi (2013)	Fuerst et al. (2015)	Brounen and Kok (2010)	Hyland et al. (2013)	

Source: Copenhagen Economics

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Appendix A
Data

In this appendix, we explain our data further details.

A.1 Variables in the models

Table 10 Variables in the models

Category	Variable	Type
Dep. variable	Sales price (P_{it})	kr. per sq m.
Price index	Quarterly price index per municipality ($Pi_{i,t}$)	kr. per sq m.
	Energy	
Measurement 1	Energy label dummies (A to F)	Dummies
Measurement 2	Energy savings compared to G-labelled houses	kWh per sq. m.
	Dummy for no energy label	Dummy
Only in model extension	Energy price given heating type in the month	kr. per kWh
	BBR: Housing structural factors	
	Size of heated housing space	sq. m.
	Size of building area	sq. m.
	Size of cadastral	sq. m.
	Size of garden area	sq. m.
	Carport (1 = "yes")	Dummy
	Garage (1 = "yes")	Dummy
	Conservatory (1 = "yes")	Dummy
	Outhouse (1 = "yes")	Dummy
	Number of buildings	Number
	Apartment building (1 = "yes")	Dummy
	More than one bathroom (1 = "yes")	Dummy
	Number of rooms	Number
	Number of floors	Number
	Basement (1 = "yes")	Dummy
	GDO: Geographical factors	
	Distance sea (1-5 dummies)	Dummies
	Distance big road (1-5 dummies)	Dummies
	Distance lake (1-5 dummies)	Dummies
	Distance forest (1-5 dummies)	Dummies
	Sea view (1 = "yes")	Dummy
	Lake view (1 = "yes")	Dummy

GC: General housing condition		
Renovation	Refurbishing year (1-3 dummies)	Dummies
Errors and omissions	Cosmetic errors and omissions (K0)	Number
	Less serious errors and omissions (K1)	Number
	Serious errors and omissions (K2)	Number
	Critical errors and omissions (K3)	Number
	To be investigated further (UN)	Number
Year of construction	Building year <1890 (1="yes")	Dummy
	Building year (1890-1930) (1="yes")	Dummy
	Building year (1931-1950) (1="yes")	Dummy
	Building year (1951-1960) (1="yes")	Dummy
	Building year (1961-1972) (1="yes")	Dummy
	Building year (1973-1978) (1="yes")	Dummy
	Building year (1979-1998) (1="yes")	Dummy
	Building year (1999-2006) (1="yes")	Dummy
Building materials	Exterior wall material (1-5 dummies)	Dummies
	Roof type (1-5 dummies)	Dummies
Heating type	District heating (1 = "yes")	Dummy
	Oil-heating (1 = "yes")	Dummy
	Natural gas-heating (1 = "yes")	Dummy
	Heating by heat pump (1 = "yes")	Dummy
	Electrical heating (1 = "yes")	Dummy
SOI: Socioeconomic factors (buyer and seller family)		
	Disposable family income	kr.
	Highest education (1-3 dummies)	Dummies
	Social sciences or technical education	Dummy
	Couple without children	Dummy
	Couple with children	Dummy
	Single with children	Dummy
	Toddlers family	Dummy
	Single toddlers family	Dummy
	More than one child family	Dummy
	Single with more than one child	Dummy

Source: Copenhagen Economics

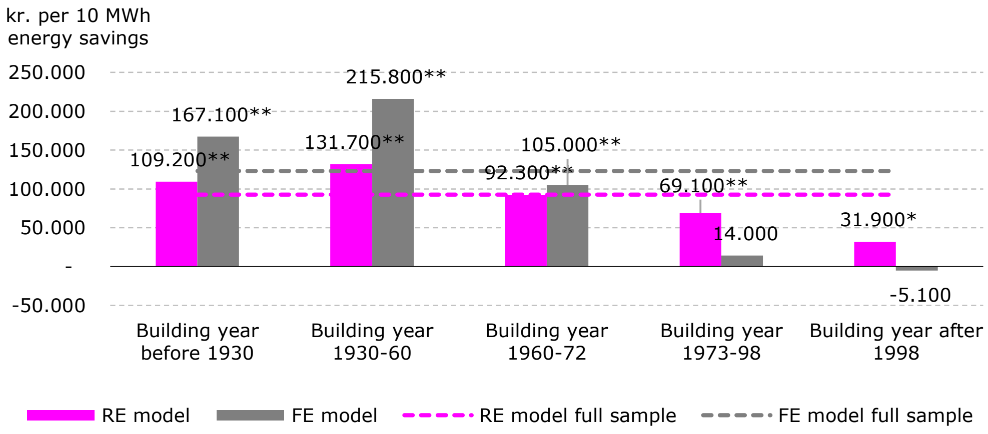
Copenhagen Economics

Appendix B
Baseline model results

In this appendix, we show some robustness and heterogeneity test for the different models.

B.2 Heterogeneity test for the RE and FE model

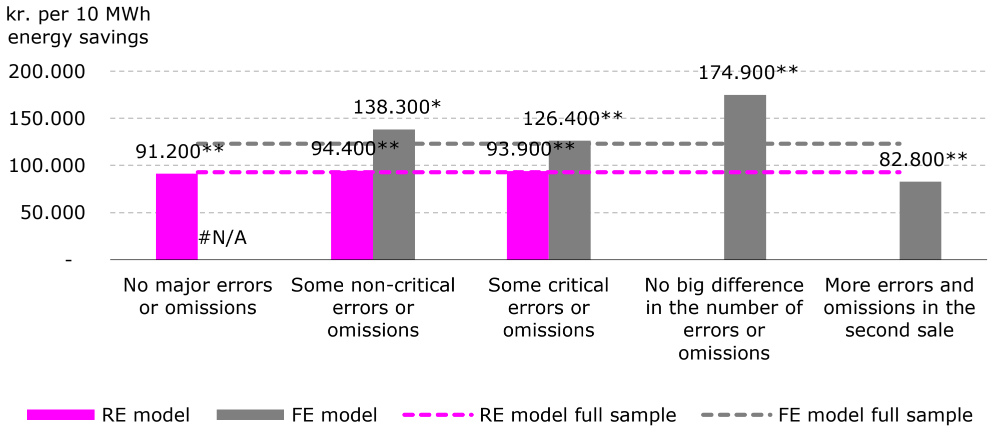
Figure 23 Analysing the RE and FE results for heterogeneity across building year



Note: The calculations relates to a 100 sq. m. house and the energy savings are relative to a G-labelled house.

Source: Copenhagen Economics

Figure 24 Analysing the RE and FE results of heterogeneity depending on reports on errors and omissions



Note: The calculations relates to a 100 sq. m. house and the energy savings are relative to a G-labelled house. We use three categories: *i*) No major errors, indicating that there are no K3 and no K2 errors. *ii*) Some non-critical errors, indicating some K2 errors but no K3 errors. *iii)* Some critical errors, indicating some K3 errors. Further, *no big difference* means that the houses does not change category between first and sec. sale and *more errors and omissions in the second sale* indicate that the house increase in category between the first and second sale. Since the number of errors and omissions change between sale, it is not possible to run the RE and FE models on all categories.

Source: Copenhagen Economics

B.3 Matching model results based on other matching principles

Table 11 Average price effects of energy labels, estimate by propensity score matching

	G->F	F->E	E->D	D->C	C->B	B->A
Nearest-neighbour	392 (3.06)	396 (4.13)	385 (4.96)	453 (4.14)	487 (1.81)	529 (0.73)
Accumulated effects	392	788	1173	1626	2113	2642
Caliper (0,001)	379 (2.99)	340 (2.88)	405 (5.31)	459 (4.43)	353 (1.34)	218 (0.29)
Accumulated effects	379	719	1124	1583	1936	2154
Kernel	372 (3.84)	408 (5.5)	473 (7.79)	434 (5.02)	424 (2.06)	712 (1.24)
Accumulated effects	372	779	1253	1687	2111	2823

Note: The numbers in parentheses are t-statistics

Source: Copenhagen Economics