Do changes in regulatory requirements for energy efficiency in single-family houses result in the expected energy savings?

Vibeke Hansen Kjaerbye
Department of Environmental, Social and Spatial Change
Roskilde University
Postboks 260,
4000 Roskilde
Denmark

Anders E. Larsen
Department of Society and Globalisation
Roskilde University
Postboks 260
4000 Roskilde
and Ea Energy Analyses
Frederiksholms Kanal 4, 4.
1220 Copenhagen K
Denmark

Mikael Togeby
Ea Energy Analyses
Frederiksholms Kanal 4, 4.
1220 Copenhagen K
Denmark

Keywords

building regulations, residential buildings, econometric evaluation, Energy Performance of Buildings Directive (EPBD), housing energy consumption, quantitative study

Abstract

This paper explores how changes in regulatory requirements for energy efficiency in buildings (in the US also known as building energy codes) affect household energy consumption. The focus in this paper is on natural gas consumption by Danish single-family owner-occupied houses. Unlike most other papers investigating household energy consumption this paper uses a unique panel data set constructed by merging several administrative data bases. The data set describes house and household characteristics, outdoor temperature and actual metered natural gas consumption over 6 years (1998-2003). Applying advanced econometric methods we examine differences in heating energy consumption due to different building regulation requirements at the time of house construction.

As for the effect of the building regulation, we find that changes in Danish building regulation standards have led to significant reductions in energy used for heating. The latest revision of the Danish building regulation covered by this paper is that of 1998. The analysis in this paper shows that a 7 percent reduction in natural gas consumption has been realised. For comparison the ex ante expectation was a 25 percent reduction in heating demand.

Introduction

Heating of households account for 25 percent of total Danish final energy demand (Danish Energy Agency 2008). The potential for energy savings is considerable and can be realised by retrofitting existing houses or through the construction of new houses. Reduction of energy consumption can be achieved e.g. by increasing house insulation, switching to low-energy windows, installing condensing boilers or other more efficient conversion technologies. Some of the improvement can be expected to be realised in response to energy prices and taxes while other parts require policy intervention.

In 2009 there were 2.735.000 dwellings in Denmark. Over the past 10 years the rate of addition of new dwellings was 0.7 percent per year. Assuming no expansion in the stock and based on these numbers it will take 139 years to renew the Danish stock of dwellings. The impact of building regulations on the energy consumption of new houses will therefore only slowly influence the total energy consumption.

Building regulations (including standards, building codes, minimum requirements, energy standards) have been used for decades in industrialized countries as a policy instrument to reduce energy consumption in buildings. In addition to energy efficiency the building regulations also include issues such as fire safety, indoor climate and other construction requirements.

Even though building energy-use regulations have been used in many countries over the years, both the pace and the details of the initiated policies are very different. E.g. Koeppel and Ürge-Vorsatz (2007) argue that although energy standards for buildings are widely used, their effectiveness varies greatly from country to country, and they do not necessarily deliver the expected energy savings.

The purpose of this paper is to add to the literature on ex post evaluation of the effect of building regulations aimed at in-

Table 1. Selected changes in building component U-values in the Danish BR.

U-values (W/C˚ m2)	BR61	BR72	BR77 (1979)	BR82	BR85 (1986)	BR98	BR08
Outer walls (>100 kg/m2)	1.1	1.00	0.40	0.40	0.35	0.30	0.30
Outer walls (<100 kg/m2)	0.50	0.60	0.30	0.30	0.30	0.20	0.20
Ceiling	0.40	0.45	0.20	0.20	0.20	0.15	0.15
Floor	0.50	0.60	0.30	0.30	0.30	0.20	0.12
Windows	-	2.90	2.90	2.90	2.90	1.80	1.5

Source: Danish Energy Agency (2009) and Togeby et al. (2008)
Note: BR77: Heating related restrictions from BR72 were in force until February 1st 1979. Restrictions from BR77 came into force on February 1st 1979.
Note: BR85. Heating related restrictions came into force April 1st 1986.

Table 2. Building component U-values in the Nordic countries.

	Component U-values (W/C˚,m2)				Overall U-values
	Ceiling	Wall	Floor	Windows	
Sweden	0.13	0.18	0.15	1.3	0.72
Denmark	0.15	0.20	0.12	1.5	0,77
Norway	0.13-0.18	0.18-0.22	0.15	0.29	0.70-0.90
Finland	0.15-0.18	0.24-0.29	0.15-0.29	1.4-1.7	0.91-1.10

Source: Togeby et. al (2008)

creasing the efficiency of space heating energy use. It is organized as follows: The next section presents the Danish Building Regulation (BR). It is followed by an attempt to put building regulations in a theoretical policy instrument frame. Then we describe previous studies. Our study is discussed in three sections: first the overall description, concentrating on the data; second, the econometric approach is laid out; third, the results are discussed. We conclude with a short discussion of broader implications and questions.

Building regulation in Denmark

Denmark has a long history of using regulatory policy instruments such as BR to reduce energy demand from buildings. The first BR to impose requirements on the energy efficiency of buildings was introduced in Denmark in 1961. Since then, requirements in the BR have been tightened in a number of steps, as shown in Table 1. Most recently, Denmark has revised the BR in order to fulfil the requirements in the Energy Performance of Building Directive (EPBD 2003).

As is true in so many fields of technological regulations, a reciprocal cause and effect relationship exists between regulations and developments in building technology. New and stricter building regulations encourage the development of new and more efficient building materials. When these become widely available, this clears the way for further tightening of the building regulation. This, for example, was the case when efficient glazing became available. Of course, in many cases technology development is international and only marginally influenced by the Danish building regulations.

Further BR has changed its focus from a net energy frame to a gross energy frame, which implies a choice between insulating and making the building efficient in retaining energy and installing renewable energy systems like solar panels that add energy without GHG emission implications.

Of relevance for household consumption of energy for heating, BR imposes restrictions on e.g. heat loss through outer walls, windows, roof and ground deck. Table 1 presents changes in building component U-values in BR since 1961.

In Table 1 we see significant reductions in allowed heat loss for all parts of the building, especially from BR61 to BR77 (in force from 1979). BR82 only changed the method for calculating heat loss. BR85 added marginal reductions, and BR98 reduced the allowed heat loss further. Under BR98 a choice can be made between complying with the reduced building component U-values or the heat loss of the entire building.

Tying the requirements to the overall energy use of the building instead of using individual requirements for each building element creates flexibility in design. The current building regulation and the planned tightening of the regulation in 2010 will promote onsite energy supply (e.g. solar heating) independently of what the alternatives may be. This could prove costly if for example the alternative is district heating based on combined heat and power production or surplus heat. At present 63 percent of all new Danish houses are supplied with district heating (Togeby et. al, 2008).

Table 2 compares the Danish U-values from Table 1 with U-values from other Nordic countries. The Danish component U-values are similar to those chosen by the other three countries.

The data set

The present paper follows the line of conditional demand studies (e.g. Baker et al. 1989, Garbacz 1985, Poyer and Williams 1993, Green et al. 1986, Munley et al. 1990, Rehdanz 2007 and Meier and Rehdanz 2008). We construct a unique panel data set by merging information from different administrative data bases about technical house characteristics, socio-economic information on households, weather conditions and actual metered energy used for heating. Our data set covers the period 1998-2003. We compare natural gas consumption used mainly for heating in houses constructed before and after changes in BR requirements. We examine factors influencing natural gas demand in single family houses and perform ex post estimations

Table 3. Definition of variables included in the models.

Variable	Definition
Lngas	Log of annual amount of natural gas used for heating, kWh
	House characteristics
Lnhousesize	Log of house size, m2
Construction period	<1930, 1931-1950, 1951-1960, 1961-1972, 1973-1978, 1979-1985, 1986-1998, 1999-2002: Unity or zero. Baseline: 1951-1960
Toilet	1, 2 or more: unity or zero. Baseline: 1
Bathroom	1, 2 or more: unity or zero. Baseline: 1
Supl_heat	Supplementary heating installation. Wood stove, solar panels, open fireplace, other, none. Unity or zero. Baseline= none
Roof	Slate, cement, tile, other. Unity or zero. Baseline = tile
Outer wall	Brick, concrete, other. Unity or zero. Baseline= brick
D_elab1	Unity in the year of energy labelling and the following years, if house is energy labelled within 1 year of house purchase, zero otherwise
Boiler_age	Age of natural gas boiler. <=10 years, >=11 years. Unity or zero. Baseline: >=11
Retrofitted	Retrofitting period: No retrofitting, <=1970, 1971-1980, 1981-90, >1991. Unity or zero. Baseline: No retrofitting
	Socio economic characteristics
Age98	Age of oldest member in household in 1998: <=20, 21-30, 31-40, 41-50, 51-60, 61-70, 71+. Unity or zero. Baseline: 21-30
Baby	Baby (<=1 year) present in household. Unity or zero. Baseline: 1
Teenager	Teenager (12-17 years) present in household. Unity or zero. Baseline:1
Lndispinc	Log to disposable income, 2003 prices, euro
Lnpers	Log to number of members in the household
	Other relevant variables
Time	Time trend. Years since 1997
Region	MidtNord (MN), HNG: unity or zero. Baseline= MN
Degreeday	Number of annual degree days
YSB	Years since the latest purchase of the house: <11, >12. Unity or zero. Baseline: <11

of energy savings caused by the revised requirements for insulation and heat loss in the Danish BR. In this study natural gas consumption in single-family houses is analyzed. Natural gas is mainly used for space heating, but also for heating water. In some houses a small amount of natural gas is used for cooking.

To be able to estimate an effect of BR on natural gas used mainly for space heating we need, first, to understand what affects energy consumption for heating in single-family houses. Table 3 lists the variables used in this paper to describe this energy consumption. Several papers (e.g. Berkhout et al. 2004) find that the insulation standard of the house plays an important role for the amount of energy used for space heating. In the models estimated in this paper we use dummy variables describing the construction period of the house to proxy the insulation standard because the period of construction determines the BR requirements for insulation that would have been met. The models also include house size in square meters, since earlier papers (e.g. Nesbakken 1999, Rehdanz 2007, Sardianou 2008, Santin et al.2009) have shown a significant positive relationship between house size and energy consumption. Further, dummy variables describe whether the house uses alternative heating supplementing the natural gas heating system. A house heated only by natural gas will use more natural gas, than a similar house that supplements with alternative heating sources such as solar panels or a wood stove. In addition, the models controls for a number of construction material options used in the house, as well as for number of bathrooms and toilets and the age of the natural gas boiler. Apart from the building characteristic variables, we also include a dummy indicating whether or not the house has received an energy label (for further information on the Danish energy labeling scheme for residential houses, see Kjaerbye 2008.) We also include a vector describing whether the house has been retrofitted and the period in which this retrofitting took place. We expect a retrofitted house to use less natural gas than a comparable non-retrofitted house. And we expect a house retrofitted after 1991 to use less natural gas that a comparable house retrofitted before 1970.

Demand for energy may also vary significantly because of differences in socio economic factors applying to the inhabitants. Thus, it has commonly been shown that higher income leads to increasing energy consumption. Hence we include a variable describing household disposable income (2003 prices). Other studies have found that elderly people prefer higher room temperature and hence use more energy for space heating. Therefore we include different age variables in our models. The literature also agrees that household size has a significant effect on the amount of energy used for space heating. Hence we include number of household members.

Apart from building characteristics and socio economic characteristics of the household, the models in this paper control for weather conditions by including data on degree-days. Degree-days measure the difference between a theoretical indoor mean temperature, 17 ˚C and outdoor mean temperature. A mean outdoor temperature of 0 ˚C for 1 day amounts to 17 degree-days.

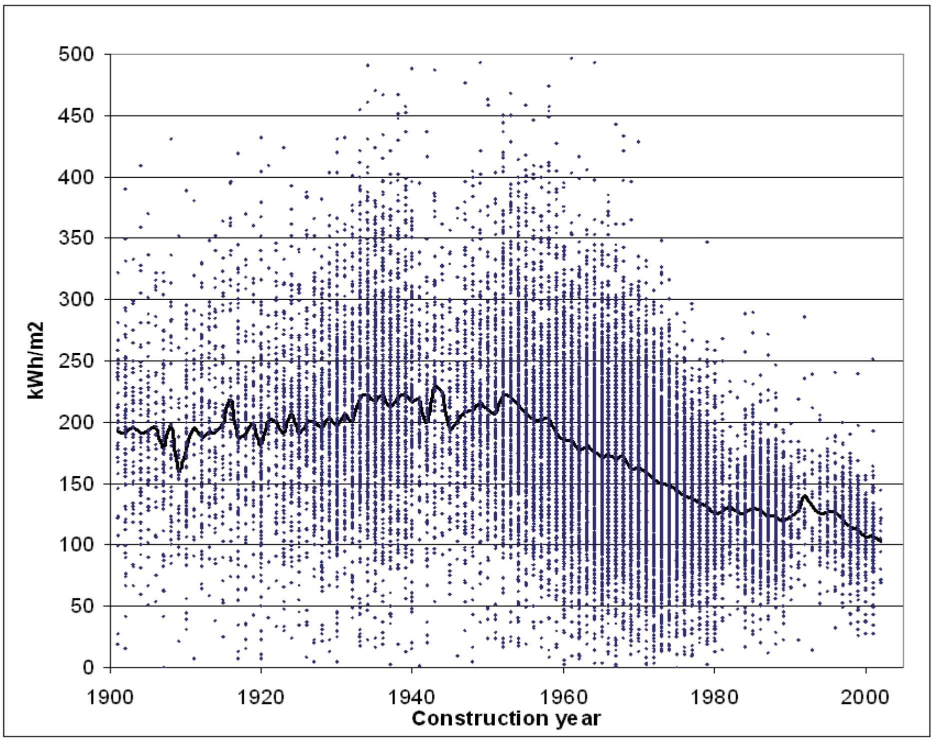

Figure 1. Yearly natural gas consumption kWh/m² in 2003 for Danish single-family houses related to construction year and the median. The solid line is the locus of the medians of all the individual observations for each year and the dots are the individual observations.

The price of natural gas (Euro/kWh) was initially merged onto the dataset.[1] This price includes taxes. Taxes for energy used in households are very high in Denmark. In round numbers the tax doubles the costs of energy in households. There was very little variation in natural gas price during this period and we ended up excluding this variable again.

From experience we expect a difference in natural gas consumption related to the duration of house ownership and hence we include a vector describing number of years since the house was bought (YSB). The longer a family has owned their house, the more time they have had to identify and install energy saving solutions. And given the assumption of rational consumers, we expect natural gas consumption to decline when YSB increases.

All socio economic characteristics are drawn from administrative registers[2]. Building characteristics are drawn from public administrative registers (BBR)[3] and data on exact energy consumption (metered consumption of natural gas) has been provided by two natural gas companies: HNG – mainly urbanized area close to the capital and Naturgas MidtNord (MN) – a more rural area)[4]. All these data are handled by Statistics Denmark, and personal identifiers were removed before our analyses.

Our panel dataset contains annual data at individual and household level for about 34,700 single-family owner-occupied houses. The houses are observed 1-6 times which results in more than 150,000 observations. The panel data constitutes a so-called un-balanced panel since the number of observations varies across houses and each building is not necessarily observed in consecutive years. 47 percent of the households are present each year in the panel, around 9 percent are only present in the first year or last year of the panel and the rest of the buildings are present in different patterns (e.g. first 5 years, last 3 years, etc.).

Figure 1 presents the relationship between yearly natural gas consumption per household and construction year of the house for a cross section sub set of our dataset – household natural gas consumption in year 2003.

Every dot in Figure 1 represents natural gas consumption for one house. Looking at the dots we see quite significant variations. The median line shows a robust decline from around 1953. The first requirements for energy efficiency were not introduced until BR61, so Figure 1 indicates that energy efficiency was already an issue in building construction before the introduction of building regulations.

The clear picture of a declining trend in household consumption of natural gas for houses constructed in later years leads us to define a set of dummy variables describing differences in construction periods. The periods are: Before1930, 1931-1950, 1951-1960, 1961-1972, 1973-1978, 1979-1985, 1986-1998 and 1999-2002.

The first three periods only represent changes in building construction traditions, whereas the later five periods both represents changes in building traditions as well as changing BR requirements related to insulation/ heat loss (Wittchen 2004).

Figure 2 presents mean yearly natural gas consumption/m² in single-family houses for the defined construction periods

1. 1 m3 gas equals 11 kWh

2. Research access available through AKF 10 percent register.

3. Data provided by Gilling Communication and Consulting (distributer of BBR data).

4. We are very grateful for confidential data provided for research by the natural gas distribution companies, HNG and Naturgas MidtNord. The two companies have now merged to one.

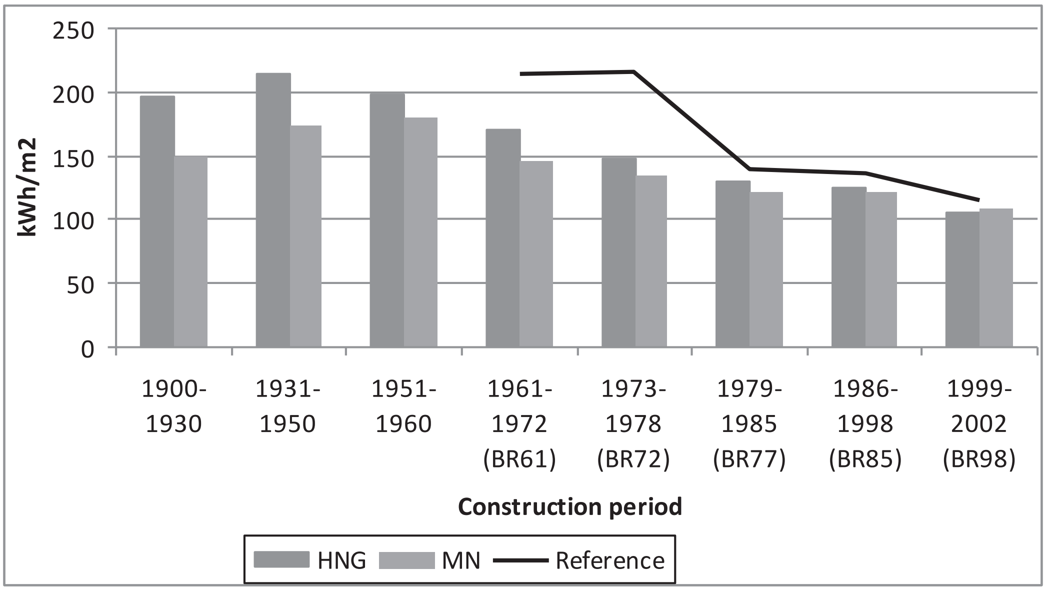

Figure 2. Mean natural gas consumption, kWh/m² in 2003 for the houses in our dataset and calculated reference according to U-values in BR.

for a cross section subset of our panel data (natural gas consumption and house size data from for all houses represented in 2003 in our dataset). We see the same picture of decreasing natural gas consumption per m² for construction starting in 1951-1960. The differences between adjacent periods are visually significant except for the two periods immediately before and after 1986. Table 1 shows that hardly any changes were introduced to required building component U-values in the 1986 BR, which might well explain this observation. Figure 2 does reveal a quite significant reduction over construction periods. Recently constructed houses use almost 50 percent less natural gas per m² than houses constructed in 1931-1950, and even the latest change (BR98) covered by our dataset show a significant reduction when comparing houses built before and after 1998.

Figure 2 also illustrates geographical differences in household energy consumption. The differences are most significant in the older stock of houses: The houses in the MN area generally use less natural gas than houses in the HNG area. Both areas include both rural and urban locations, and any systematic differences in size and construction timing have been removed by the treatment of the data. One explanation of this difference could be that households in the MN area have lower income. Therefore they might either choose to have a lower indoor temperature or heat their homes with alternative energy sources like fireplaces. To take account of the effect of income on household energy demand, data describing household income is included the statistical models in this paper. Unfortunately data on indoor temperature does not exist, so we cannot control for the potential correlation between income and indoor temperature. As far as alternative energy sources have been registered correctly in the registers, we can take account for potential difference in energy consumption by applying a set of dummy variables describing the existence of alternative energy sources. Other parameters affecting the geographical differences in energy consumption are family composition and age of family members. Data describing these differences are also used in our models. Further differences in the two areas are unknown and can only be included in the estimations as a dummy variable describing geographical location.

The reference line in Figure 2 is calculated as the level of natural gas that would have been used in a standard 145 m² house built in different construction periods according to the U-values in the building regulations. The calculations incorporate natural gas used to heat water, heat loss because of ventilation and boiler loss. For houses constructed according to the BR61 we see a significant difference between the reference line and the mean natural gas consumption. This probably indicates that a major part of the houses built in this period have been improved and are now more energy efficient. For more recent constructed houses the difference between reference line and mean natural gas consumption decreases. But even in the last period we do not see a perfect match between real mean natural gas consumption and expected natural gas consumption level according to U-values in the building regulation.

So far we have only described differences in natural gas consumption related to construction year and location. Other factors are known to influence household energy consumption. Tables 4 presents mean values for relevant characteristics of the subsamples and for the total dataset, and illustrates there are at least modest variations across the construction periods of the socioeconomic characteristics of the inhabitants of the covered houses (again we present means calculated on the 2003 cross section dataset). As mentioned earlier most houses are represented in several years of the panel dataset.

Table 4 shows that houses constructed 1951-60 are the smallest houses and they are on average 29 m² smaller than the largest houses, which are constructed 1999-2002. The Table also shows that younger people with lower disposable income occupy new houses and this could very well explain some of the differences in energy consumption between construction periods.

Table 4. Mean values for selected characteristics in the 2003 cross section dataset.

	Construction period ((BR – building regulation in force at the time in question)								
	All houses	-1930	1931-50	1951-60	1961-72 (BR61)	1973-78 (BR72)	1979-85 (BR77)	1986-98 (BR85)	1999-02 (BR98)
House size, m^2	145	156	132	128	145	153	149	150	161
Disposable income, 1,000 Euro, 2003 prices	52.9	55.9	54.4	51.1	51.5	51.2	58.0	56.5	49.6
Household members	2.22	2.23	2.23	2.19	2.18	2.23	2.31	2.35	2.40
Age of oldest household member	48.8	47.1	47.1	49.9	50.9	48.7	47.0	44.5	41.9
N, number of houses observed in 2003	26,792	3,262	3,261	3,442	9,631	4,075	1,373	1,426	322
All years	150,553	18,253	17,896	19,359	55,678	23,069	7,688	7,835	775

Econometric approach

We estimate an energy demand model for the consumption of natural gas at household level, and we do so only for households using natural gas for heating. Consumption of natural gas is specified as a function of building characteristics (including boiler age and e.g. retrofitting period), socio-economic characteristics, location, weather and a time indicator:

$$Ln(E_{it}) = \alpha + \beta_B B_{it} + \beta_S S_{it} + \beta_W W_t + \beta_R R_i + \beta_T T_{it} + \beta_L L_{it} + \upsilon_i + \varepsilon_{it}$$

where E_{it} is natural gas consumption in kWh/m² for building i at year t. B_{it} is a vector of building characteristics for building i at year t. S_{it} is a vector of socio-economic characteristics of the household living in building i at year t. W_t is mean national degree days for year t. R_i describes geographic location. T is a time trend assumed to explain any unobserved year-specific factors affecting household energy demand. L_{it} is a dummy taking the value 1 from year t and onwards if building i has received an energy label in year t or previously. υ_i is a building and household specific term that includes time constant characteristics for both building and household that are not explained by the variables included in the model. This may include level of maintenance of the house and household norms and attitudes towards energy consumption. ε_{it} is a random mean-zero symmetrically distributed error-term. This term may include unobserved time-varying characteristics like income fluctuations. A full description of included variables can be found in Table 3. After running a large number of regressions, we eliminated the gas price variable because it hardly varied over time.

As in standard neo-classical micro-economic demand models, we assume the households behave so as to maximize utility subject to external constraints and given prices.

The two main micro-econometric approaches to the fitting of models using panel data are fixed effect (FE) regressions and random effects (RE) regressions. FE regressions can be estimated in three versions; within-groups-regression model, first-differences regression and least squares dummy variable regression. All three approaches eliminate all time-constant variables, hence it becomes impossible to estimate any coefficients for variables that are constant over time for each building (Woolridge 2002). In our case where some of the key variables (house size, vintage class construction materials) are more or less constant over time for the individual building, a FE model can lead to imprecise estimates (Woolridge 2002). An alternative approach is the RE regressions. Given our interest in the effect of both time-constant variables and time-varying variables, the FE estimator is practically useless, and RE is our only choice. So based on Woolridge (2002), and in line with Meier and Rehdanz (2008), we specify our model in the RE form. We estimate the resulting energy demand models on our panel dataset and use the estimated energy demand model in ex post evaluations of changes in BR.

Results

First, we present differences and similarities in the estimated energy demand model when using different econometric approaches. The dependent variable in every case is the logarithm of annual household natural gas consumption. We start with the simplest regression; an OLS cross section regression estimating energy demand using only data from the 2003 cross section data set (OLS_2003). We expand the regression by running an OLS using the total panel data set, this is done by using the panel-corrected least squares invoked by the "cluster" option in STATA (OLS_cluster). This deals with any correlation between disturbances from observations drawn from the same household as well as providing heteroscedasticity-consistent standard errors. From this we move on to one of the main micro-econometric approaches to the fitting of models using panel data; random effects (RE) regressions. We present selected parameter estimates from all approaches to illustrate differences and similarities between the parameter estimates of the models and investigate how insensitive our parameter estimates are to the choice of econometric approach.

Table 5 shows differences and similarities between the three different econometric estimation methods. For the variables with estimated coefficients, we see a quite robust pattern in both sign and size of significant parameter estimates. Comparing significant (at 1 percent level) parameter estimates in the OLS, OLS cluster and RE regressions for the 2003 cross section

Table 5. Regression coefficients for OLS 2003 cross section and panel data analysis by OLS cluster and RE models.

Dependent variable= logarithm of annual household natural gas consumption (kWh) (lngas)			
	OLS_2003	OLS_cluster	RE
Degreeday	-	0.0002***	0.0002***
Lnhousesize	0.4774***	0.4714***	0.5073***
Lndispinc	0.0775***	0.0563***	0.0207***
Vintage<30	0.0165	0.0101	0.0034
Vintage31-50	0.0526***	0.0294***	0.0250**
Vintage61-72	-0.0966***	-0.0911***	-0.0968***
Vintage73-78	-0.1889***	-0.1838***	-0.2102***
Vintage79-85	-0.3214***	-0.3180***	-0.3420***
Vintage86-98	-0.3451***	-0.3624***	-0.3667***
Vintage99-02	-0.3687***	-0.3946***	-0.4385***
HNG	0.1117***	0.0769***	0.0772***
Boiler_age10	-0.0595***	-0.0454***	-0.0076**
YSB<11	-0.0356***	-0.0288***	-0.0054
D_retro<=70	0.0233*	0.0165	0.0225*
D_retro71-80	-0.0252**	-0.0254***	-0.0239***
D_retro81-90	-0.0622***	-0.0711***	-0.0713***
D_retro>=91	-0.0714***	-0.0854***	-0.0940***
Age<=20	0.1513***	0.1250***	0.0780***
Age31-40	0.0421***	0.0158*	0.0068
Age41-50	0.0592***	0.0385***	0.0207*
Age51-60	0.0568***	0.0404***	0.0093
Age61-70	0.1107***	0.0817***	0.0455***
Age>=71	0.2169***	0.1707***	0.1117***
Lnpers	-0.0184	-0.0027	0.0315***
Time trend	-	-0.0157***	-0.0094***
D_elab1	-0.0578***	-0.0639***	-0.0825***
_cons	6.8923***	6.7801***	6.8924***
N	26.792	150.552	150.552
r2	0.2428	0.2338	

Note: ***: significance at 1 percent, **: significance at 5 percent and *: significance at 10 percent
Note: A number of additional variables not reported here have been included in the estimations. These are a set of dummy variables describing outer wall material, a set of dummy variables describing roof material, a set of dummy variables describing number of toilets, a set of dummy variables describing number of bathrooms, a set of dummies describing sources of supplementary heating, a set of dummy variables for presence of one or more babies and a set of dummies for presence of one or more teenagers. The reference is a household where the oldest member is 21-30 years old, living in a house built between 1951-1960, that has not been retrofitted. The house has one toilet and one bathroom, there are no supplementary heating sources.

data set, we see the same sign and size for most of the significant parameter estimates.

Based on technological development we expect that an older gas boiler uses more natural gas to produce the same heating result. A significant negative sign on the variable *boiler_age10* (age of boiler < 10 years compared to an older boiler) in Table 5 confirms this.

A paper on energy labelling of single-family houses (Kjaerbye 2008) found no significant effect of energy labelling, but this lack of effect could very possibly be caused by selection. If the energy efficient houses are those whom mostly present energy labels then the significant negative signs in Table 5 are what would be expected.

As concluded in the econometric approach section and illustrated in Table 5, parameter estimates from the OLS_2003 model are only estimated on the 2003 sub sample. OLS_cluster and RE both provides parameter estimates estimated by using the entire panel dataset. But whereas the OLS_cluster model uses a random order of the yearly household observations, the RE model takes account of the non-random order of these observations. As we wish to use as much information as possible from the panel dataset, we continue exploring the dataset by using the estimated RE model.

In Table 5 we see significant effects of several of our time constant variables. E.g. the results suggest a strong positive effect of house size on the consumption of natural gas. This is

Figure 3. Estimated household natural gas consumption kWh/m² per year calculated for a comparable standard house constructed in different periods

also found in earlier papers. The parameter estimates presented in Table 5 also suggest a significant relationship between construction period and the amount of natural gas used. As we saw in Figures 2 and 3, the results suggest that houses constructed between 1998-2002 uses significantly less natural gas than houses constructed earlier.

To illustrate the differences between construction periods, the predicted amount of natural gas used in a standard house is calculated for each of the construction periods based on the significant (at 1 percent level) parameter estimates from Table 5. The same house/household specification is used for all construction periods. The only difference is therefore unobserved characteristics like insulation and type of windows. The standard house is described using mean values from the 2003 cross section data set. The house is 145 m² and it is situated in the HNG area. Disposable household income is 52,868 Euro, three people are living in the house, and the oldest member of the household is 49 years old. Further the house is brick with tile roof, one bathroom and no supplementary heating. The natural gas boiler is less than 10 years old, and the house has been traded within the last 10 years but not retrofitted. Figure 3 shows the predicted amount of natural gas (kWh/m²) used in the specified standard house. The dotted vertical lines refer to limits between the defined construction periods, and for the later periods they also represents years of changes in BR.

Figure 3 graphs the estimated age effect based on the parameter estimates from Table 5 and the standard house specification. The estimated age effect appears to be robust to the specification of other parts of the model. The graph show significant reductions in energy consumption for houses built from 1961 and onwards, implying that building regulations have absolutely had an effect on household natural gas consumption.

The effect of construction period and building regulations confirms what was found in an earlier study based on a smaller cross section dataset (Leth-Petersen 2002). The paper found that houses constructed after the introduction of BR79 use significant less energy than houses constructed before. We find that not only does the BR79 result in declining energy consumption, but so also do the earlier BR72, and the later BR85 and BR98.

Based on this standard house an ex post estimation of saved energy because of BR changes can be carried out. In this approach it is assumed that all houses built before a BR change are constructed according to the requirements in the old BR. And all houses constructed after a BR change are constructed to meet the new and stricter requirements. Table 6 presents this ex post estimation.

The estimated amounts of household natural gas consumption (kWh/m²) are used in Table 6 to evaluate the effect of changes in BR on household energy consumption. Based on the data and models used in this paper we find that every construction period has led to declining energy consumption. The numbers presented show that the change in BR98 has led to a reduction of 7 percent when comparing houses constructed in the period before 1999 and houses constructed in 1999-2002.

Discussion

We have illustrated how changing requirements in Denmark's BR have led to lower natural gas consumption. Especially the earlier restrictions have resulted in large natural gas savings in today's building stock. Our analysis shows that changes in BR

Table 6. Estimated changes in household natural gas consumption due to changes in building regulations.

	Construction period (BR – building regulation in force at the time in question)							
	-1930	1931-50	1951-60	1961-72 (BR61)	1973-78 (BR72)	1979-85 (BR77)	1986-98 (BR85)	1999-02 (BR98)
Yearly kWh	29209	29847	29110	26424	23591	20678	20174	18776
Yearly kWh/m^2	201	206	201	182	163	143	139	129
Difference from prior period - kwh/m^2		4	-5	-19	-20	-20	-3	-10
Difference from prior period, percent		2%	-2%	-9%	-11%	-12%	-2%	-7%
Total national m^2 of constructed single family during period (1,000 m^2)	37,977	16,822	11,981	8,458	20,423	9,582	6,872	3,309

Source: Statistics Denmark, 2009 and own calculations

standards have an effect. A question is whether the BR lives fully up to the expectations. That is not so. According to Danish Energy Agency (1990) the plan for a revision of insulation standards in BR98 should result in a 25 percent reduction in energy used for heating in new houses. The estimates in this paper show a decline in natural gas consumption at only 7 percent.

There is no question that stricter building regulations over time lead to a more energy efficient house stock. But in the short run, we will only see minor changes. If it is a priority to make the building stock more energy efficient, there is no way around focusing on the existing buildings, that still many years from now will account for the major part of the building stock.

In other parts of the world, where economic development has caused a boom in building constructions, strong building regulations with strong enforcement will be a key element for achieving an energy efficient building stock.

In the recent years energy consumption in buildings has gained growing interest by researchers and politicians. Several studies have been published suggesting a market transformation to better target the energy saving potential in the building stock. Transformation of the market in terms of a combination of policy instruments (regulatory instruments, information instruments, financial/fiscal incentives and voluntary agreements) is thought to be the key to achieve energy reductions in the building sector. The idea behind market transformation is to use a coordinated suite of tools to transform the market in which building design, construction, and operation occurs. In practice it is difficult to discern exactly how to coordinate these policy tools, but the idea of a multi-pronged approach does seem to fit with the diverse interests and elements in the building industry (Janda 2009).

The EPBD (Energy Performance of Buildings Directive) and the recent recast of the EPBD give much stress to building regulations, and time frames are given for when new built houses have to meet the requirements for energy neutrality. Also this underlines the importance of the BR as a tool for governments to live up to the EPBD and careful evaluations of the effect.

References

Baker, P., Blundell and R., Mickelwright, J., 1989: Modelling household energy expenditure using microdata. Economic Journal, 99, pp. 720-738.

Berkhout, P.H.G., A. Ferrer-I-Carbonell and J.C. Muskens 2004: The ex post impact of an energy tax on household energy demand. Energy Economics, 26, pp. 297-317.

Danish Energy Agency, 1990: Energi2000. Handlingsplan for en bæredygtig udvikling. Only available in Danish.

Danish Energy Agency, 2008: Energy Statistics 2008. http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/Energi%C3%B8konomi%20og%20-statistik/2009/HTML/energi_08/index.htm

Danish Energy Agency, 2009: Appendix to Handbook for Energy Consultants 2008. Only available in Danish. http://www.femsek.dk/graphics/FEM_Sekretariatet/H%E5ndbog/EM-HB/HB2008_v2/HB2008_bilag_oplaeg_ver4.pdf

EPBD, 2003: The Directive 2002/91/EC. European Commission.

Garbacz, C., 1985: Residential fuel oil demand: A micro-based national model. Applied Economics, 17, pp. 669-674.

Green, R.D., A.G. Salley, G. Grass, and A.A. Osei, 1986: The demand for heating fuels: a disaggregated modelling approach. Atlantic Economic Journal, 14(4), December, pp. 1-14.

Janda, K., 2009: Worldwide status of energy standards for buildings: a 2009 update. ECEEE 2009 Summer Study. Pp. 485-491.

Kjaerbye, V.H., 2008: Does energy labeling on residential housing cause energy savings ? AKF working paper. Also published in: ECEEE 2009 Summer Study, pp. 527-537.

Koeppel, S. and D. Ürge-Vorsatz, 2007: Assesment of policy instruments for reducing greenhouse gas emissions from buildings. Report for the UNEP-Sustainable Buildings and Construction Initiative. Central European University: Budapest. http//web.ceu.hu/envsci/projects/UNEP/index.html

Leth-Petersen, S., 2002: Micro econometric modelling of household energy use: testing for dependence between demand for electricity and natural gas. The Energy Journal, 23, No 4, pp. 57-84.

Meier, H. and K. Rehdanz, 2008: Determinants of residential space heating expenditures in Great Britain. Energy Economics, In Press, Corrected Proof, Available online 27 November 2009.

Munley, G.M., L.W. Taylor and J.P. Formby, 1990: Electricity Demand in multi-family renter-occupied residences. Southern Economic Journal, 57 (1).

Nesbakken, R. 1999: Price sensitivity of residential energy consumption in Norway. Energy Economics, 21, pp. 493-515.

Poyer, D.A: and M. Williams, 1993: Residential energy demand: additional empirical evidence by minority household type. Energy Economics, 15, pp. 93-100.

Rehdanz, K., 2007: Determinants of Residential Space Heating expenditures in Germany. Energy Economics, 29, pp. 167-182.

Santin, O.G., L. Itard and H. Visscher 2009: The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings, 41, pp. 1223-1232

Sardianou, E. 2008: Estimating space heating determinants: An analysis of Greek households. Energy and Buildings, 40, pp. 1084-1093

Statistics Denmark, 2009: StatBank Denmark. Table BYGB3. Areas of the building stock by region, use, area and year of construction.

Togeby et al, 2008: En vej til flere og billigere energispareaktiviteter. Udarbejdet af Ea Energianalyse, NIRAS, RUC og 4-Fact. Copenhagen. Only available in Danish.

Wittchen, K.B., 2004: Heating energy savings in dwellings. Danish Building Research Institute. Aalborg University. Only available in Danish.

Woolridge, Jeffrey M., 2002: Econometric analysis of cross section and panel data. Massachusetts Institute of Technology

Acknowledgements

We would like to thank Professor Cliff Russell from Vanderbilt University, Professor Søren Leth-Petersen from Copenhagen University and two anonymous referees for the eceee 2011 Summer Study for many highly valuable comments on this paper. We also thank The Danish Energy Agency, AKF and Roskilde University for financing the study.