Ea Energianalyse

The effect of building regulations on energy consumption in single-family houses in Denmark

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1 Sammenfatning

Denne rapport analyserer, i hvilket omfang stramninger i Bygningsreglementets energidel påvirker husholdningernes energiforbrug. Fokus for rapporten er danske enfamiliehuse. I modsætning til mange andre analyser heraf, bruger vi i denne rapport unikke paneldata, der er konstrueret ved at sammenkæde flere administrative registre. Vores data beskriver bl.a. husholdningernes karakteristika, udendørstemperatur og ikke mindst forbruget af naturgas i en periode på 6 år (1998 til 2003).

Ved at bruge avancerede økonometriske metoder kan vi finde forskelle i energiforbrug relateret til det bygningsreglement, der gjaldt, da huset blev bygget.

Med hensyn til effekten af bygningsreglementet har vi fundet, at stramninger rent faktisk leder til reduceret energiforbrug. De tidligere stramninger har haft relativt større betydning; dels havde de i sig selv en større effekt på nye huse, og dels har de haft længere tid til at virke i, set i forhold til den samlede bestand af enfamiliehuse.

Den sidste stramning af Bygningsreglementet, der er dækket af denne rapport, er revisionen fra 1998. Denne stramning resulterede i en 7 pct. reduktion af forbruget af naturgas til opvarmning i nye boliger bygget efter dette Bygningsreglement.

Der er således ikke tvivl om, at stramninger i Bygningsreglementet leder til reduceret energiforbrug til opvarmning. Men da den årlige tilgang af nye boliger udgør under 1 pct. af den samlede boligmasse, er det helt afgørende på kort og mellemlangt sigt også at fokusere på den eksisterende boligmasse, der i mange år fortsat vil være den største del af boligmassen.

I andre dele af verdenen, hvor den økonomiske udvikling har forårsaget et boom i boligbyggeriet, vil en stram regulering af boligbyggeriet være et afgørende element for at realisere en effektiv boligmasse.

I EU er der inden for rammerne af EPBD (Energy Performance of Buildings Directive) givet tidsrammer for, hvornår nye huse forventes at være energineutrale. Her er et centralt virkemiddel Bygningsreglementet. Dette understreger dels, at Bygningsreglementet er et centralt virkemiddel, og dels at der er behov for omhyggelige evalueringer af effekten.

Afslutningsvis skal det understreges, at stramninger af Bygningsreglementet ikke per definition er omkostningseffektivt i forhold til at reducere CO_2-udledningen i forbindelse med opvarmning. Stramninger af Bygningsreglementet vil her skulle sammenlignes med investeringer i vedvarende energi, f.eks. solvarme og solceller på huset, og sammenlignes med fjernvarme baseret på vedvarende energi, f.eks. biomasse, geotermi og solvarme i stor skala.

2 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 regulations 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. This revision has resulted in a 7 pct. reduction in natural gas consumption.

3 Introduction

Heating of households account for 25 per cent of total Danish final energy demand (Danish Energy Agency 2008). The potential for energy saving 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 dwelling was 0.7 pct. 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 regulation 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 buildings regulations aimed at increasing 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 regulation in a theoretical policy instrument frame. Then we describe present 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.

4 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 become 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 marginal 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 insolating 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.

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.

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 pct. of all new Danish houses are supplied with district heating (Aggerholm, 2008, Togeby et. al, 2008)

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)

Table 2 compares the Danish U-values from table1 with U-values from other Nordic countries. The Danish component U-values are similar to those chosen by the other three countries.

5 Building regulations as a policy instrument

There are many distinctions drawn in discussions of the relative merits of policy instrument alternatives. Traditionally, in environmental economics the focus has been on two categories of policy instruments:

- command and control (e.g. prohibitions or technology specifications) and
- economic (e.g. pollution charges or cap and trade).

This distinction is made in textbooks in environmental economics, e.g. Pearce and Turner (1990). Both these categories are very broad. Command and control encompasses e.g. the prescription for catalytic converters in car exhaust systems and the EU-ban on incandescent lamps. Economic instruments cover e.g. pollution charges, treatment subsidies as well as tax breaks for installing ceratin energy technologies. While the categories are very broad, however, they are not broad enough to encompass the newer notion of information provision as a tool of policy.

Vedung (2000) repairs the problem with information as a policy instrument and consider three types of policy instruments:

- regulation, the stick (e.g. minimum efficiency standard),
- economic instruments, the carrot and
- informative instruments, the sermon

Our experience is that these three types cover all policy instruments in general use. See e.g. Togeby et.al. 2008, where all Danish policy instruments used in the policy for energy efficiency are grouped in these three groups. The three groups however are still very encompassing so it is still not possible to say anything general about effectiveness, let alone efficiency based for any of the groups.

One can draw finer distinctions, as does Russell in “Applying Economics to the Environment” Russell (2001). He consider 10 different policy instruments: 1. Prohibition, 2. Technology specification, 3. Technological basis for discharge standard, 4. Performance specification, 5. Tradable performance specification (tradable permits, 6. Pollution charges, 7. Subsidies, 8. Liability law provisions, 9. Provision of information, 10. Challenge regulation and voluntary agreements. But even with the ten categories he suggests, it is at best possible only to suggest broad limits on what can be claimed for specific members of one or another category.

In this characterisation the Danish building regulation has moved from being a technology specification (prescribing the standard of the materials used) to a performance specification in BR 98 (prescribing the outcome of the energy saving effort for the whole building). The implication is that the latter approach at least has a better chance of producing an efficient outcome than one that specifies a particular technology.

More broadly, the BR of any form can be rational because information often is a public good with the attribute of non-rival consumption and non-excludability (Stiglitz, 2000). A public good will be under provided and under consumed without government interference in the market e.g. with provision of the information. Or in every day terminology: Households and firms are unable to afford a major engineering staff to find a reasonable state of the art of what is possible with reasonable cost. It would not be efficient to force them to try, either from a household perspective or from a social perspective.

Said another way, in an economic discussion of the rational choice of policy instrument the overall idea is to leave as many optimisation possibilities to the market (households and firms) as possible (Stiglitz, 2000). With the intention of leaving more choices to the households and firms the Danish move from technology specification to performance specification is a move in the right direction.

A theoretic reason for making the BR a technology specification or a performance specification (and not only providing the information behind the specification) probably is the very long lasting commitment of the Danish government to reducing energy consumption and its newer commitment to reducing CO2-emmissions.

In Bemelmans-Videc (2003) the following rule is suggested: “Politicians have a strong tendency to respond to policy issues by moving successively from the least coercive policy instrument (e.g. information) to the most coercive (e.g. a standard)”. This is what has happened in Denmark with the Building Regulation. The BR 1961 was very simple to comply with, whereas the newest and the upcoming revisions are challenging to obey ref figure 3.

6 Previous studies

There is a vast literature on residential energy demand. The studies can be divided into two main groups. Some concentrate on mixed discrete/continuous modeling of energy demand, and others on conditional demand. The work on mixed discrete/ continuous models makes clear that decisions concerning energy consumption should distinguish between demand for appliances using energy (discrete) and demand for energy itself, caused by the use of these appliances (continuous). Among the most important such studies using micro data are Dubin and Macfadden (1984) and Dubin (1985). A more recent study along this line is Nesbakken (2001), who uses Norwegian data. Bernard et al. (1996), Lee and Singh (1994), Baker and Blundell (1991) are other examples of studies using mixed discrete/continuous modeling of energy demand.

Conditional demand studies concentrate on the continuous demand for energy conditional on a given technology. Examples include Baker et al. (1989), Branch (1993), Garbacz (1983, 1985), Poyer and Williams (1993), Klein (1988), Green (1987), Green et al. (1986), Munley et al. (1990). More recent papers e.g. Rehdanz (2007) using German cross-section data explicitly considering the influence of socio-economic characteristics on households' space heating demand; and Meier and Rehdanz (2008) using a British panel dataset for investigating households' demand for heating.

For Denmark two relevant studies have been conducted; Leth-Petersen and Togeby (2001) and Leth-Petersen (2002).The first paper used Danish panel data on energy used for heating in apartment blocks. The study only included technical information on building level, and did not consider socio-economic information on households. The second paper (Leth-Petersen 2002) includes socio-economic information but only in a cross-section dataset of single-family houses and only for fulltime employed couples in single-family houses.

Relevant results from theses papers and others on estimated models of residential energy consumption are presented in appendix 1.

7 The Present Study

The present paper follows the line of conditional demand studies. 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 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 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 (see appendix 1) 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.

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

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 papers listed in appendix 1 also agree 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.

Also the price of natural gas (euro/kWh) is 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 is very little variation in natural gas price during this period.

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 and 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 increase.

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) have 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 per cent of the households are present each year in the panel, around 9 per cent are only present in the first year or last year of the

[1] 1 m^3 gas equals 11 kWh
[2] Research access available through AKF 10% 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.

panel and the rest of the buildings are present in different patterns (e.g. first 5 years, last 3 years, etc.).

Figure 2 presents the relationship between yearly natural gas consumption per household and construction year of the house for the 2003 cross section sub set of our dataset.

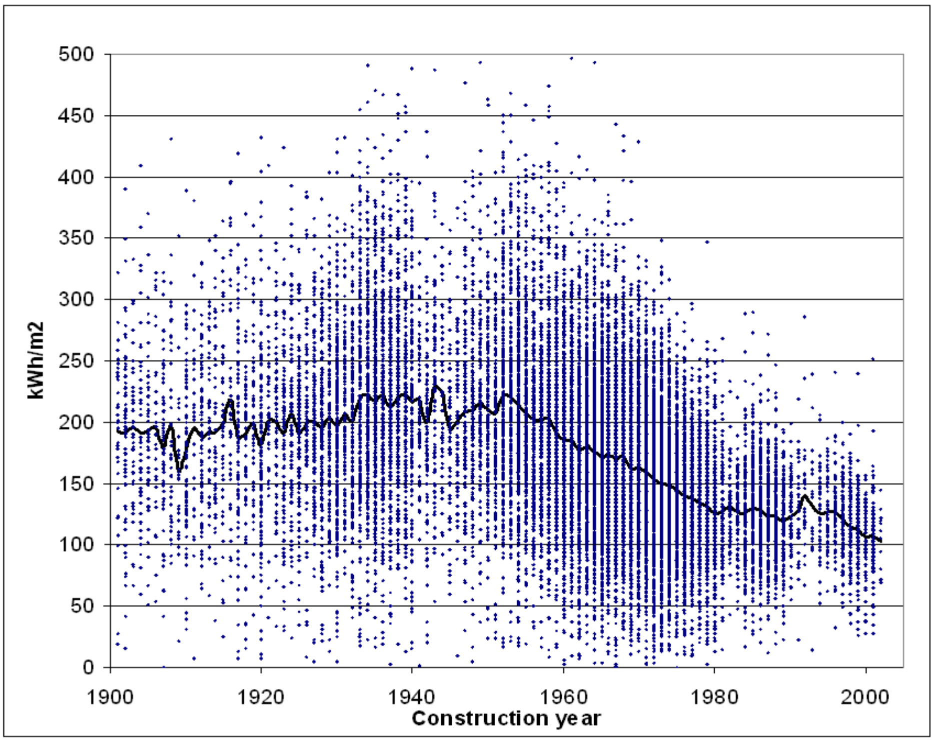

Figure 2 Yearly natural gas consumption kWh/m² in 2003 for Danish single-family houses related to construction year and the median. The solid line is the locus of the medians of all the individual observations for each year and the dots are the individual observations

Every dot in figure 2 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 2 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 3 presents mean yearly natural gas consumption/m^2 in single-family houses for the defined construction periods 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 m^2 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 was introduced to required building component U-values in the 1986 BR, which might well this observation. Figure 3 does reveal a quite significant reduction over construction periods. Recently constructed houses use almost 50 per cent less natural gas per m^2 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.

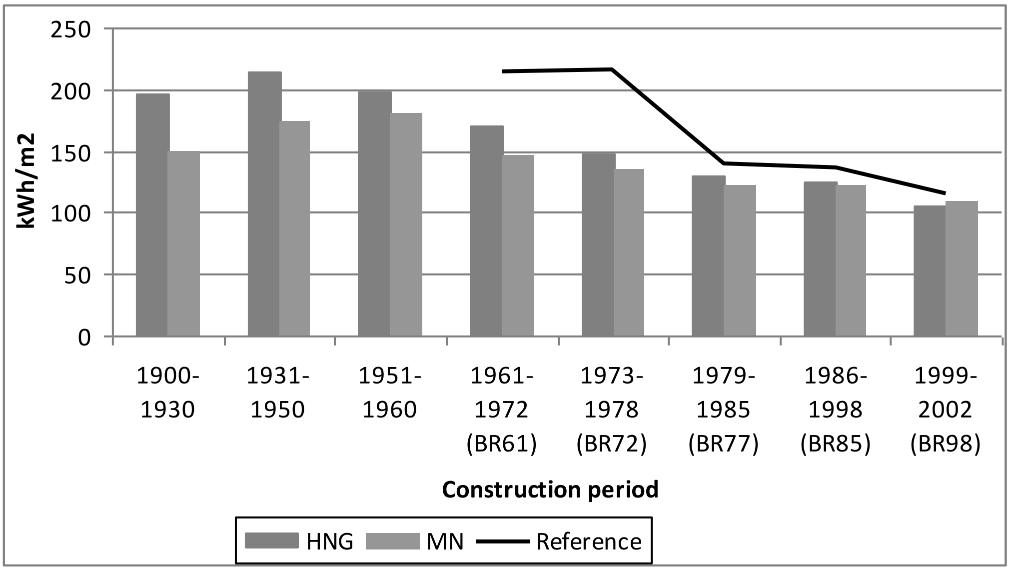

Figure 3 Mean natural gas consumption, kWh/m^2 in 2003 for the houses in our dataset and calculated reference according to U-values in BR

Figure 3 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. Data describing household income is used in our models. Unfortunately data on indoor temperature does not exist, so we cannot control for that parameter. 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 unknown and can only be included in the estimations as a dummy variable describing geographical location.

The reference line in figure 3 is calculated as the level of natural gas that would have been used in a standard 145 m^2 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.

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 below 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 Mean values for selected characteristics in the 2003 cross section dataset

	Construction period								
	All houses	-1930	1931-50	1951-60	1961-72	1973-78	1979-85	1986-98	1999-02
House size, m2	145	156	132	128	145	153	149	150	161
Disposable income, 1,000 €, 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

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. Other important characteristics like disposable income and age of oldest household member also vary quite significant across the subsamples.

8 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 appendix 2. After running a large number of regressions, we eliminated the gas price variable because it did hardly vary 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 fixed effects 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 both for our total panel dataset and for subsamples representing different groups of construction periods. Then we use the estimated energy demand models in ex post evaluations of changes in BR.

9 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 the two main micro-econometric approaches to the fitting of models using panel data; fixed effect (FE) regressions and random effects (RE) regressions. We present selected parameter estimates from all four 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 Regression coefficients for OLS 2003 cross section and panel data analysis by OLS cluster, RE and FE models

Dependent variable= logarithm of annual household natural gas consumption (kWh) (lngas)				
	OLS_2003	OLS_cluster	FE	RE
Degreeday	-	0.0002***	0.0002***	0.0002***
Lnhousesize	0.4774***	0.4714***	-	0.5073***
Lndispinc	0.0775***	0.0563***	0.0157***	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***	0.0089**	-0.0076**
YSB<11	-0.0356***	-0.0288***	0.0017	-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***	0.0606**	0.0780***
Age31-40	0.0421***	0.0158*	-0.0033	0.0068

Age41-50	0.0592***	0.0385***	-0.0033	0.0207*
Age51-60	0.0568***	0.0404***	-0.0410	0.0093
Age61-70	0.1107***	0.0817***	-0.0036	0.0455***
Age>=71	0.2169***	0.1707***	0.0144	0.1117***
Lnpers	-0.0184	-0.0027	0.0513***	0.0315***
Time trend	-	-0.0157***	-0.0079***	-0.0094***
D_elab1	-0.0578***	-0.0639***	-0.0896***	-0.0825***
_cons	6.8923***	6.7801***	9.3475***	6.8924***
N	26.792	150.552	150.552	150.552
r2	0.2428	0.2338	0.0552	
r2_o			0.0118	0.2296
r2_b			0.0027	0.2477
r2_w			0.0552	0.0542

Note: ***: significance at 1%, **: significance at 5% and *: significance at 10%
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.

Table 5 shows differences and similarities between the four different econometric estimation methods. As expected we see that a large fraction of our variables do not have estimated coefficients in the FE model because of their time invariant structures. 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 pct. level) parameter estimates in the OLS, OLS cluster and RE regressions for the 2003 cross section data set, we see the same sign and size for most of the significant parameter estimates.

Based on earlier findings listed in appendix 1 we expect to find a positive sign on the variables describing house size, income and house age. The estimations presented in table 5 confirm these earlier findings. Based on figure 3 we expect houses situated in the HNG area to use more natural gas than the MN houses. This is confirmed by a significant positive sign on *HNG.* Further we expect by intuition that an older gas boiler to use more natural gas to produce the same heating result.. This is also confirmed by table 5, where we see a significant negative sign on *boiler_age10* (age of boiler < 10 years compared to an older boiler).

Based on the findings in Kjaerbye (2008) we expect to find no significant sign on the variable describing whether the house has been energy labeled. Interestingly we actually find significant negative signs in all four estimations.

The table also presents overall R^2 (r2_o), R^2 between variation (r2_b) and R^2 within variation (r2_w). The results show that the largest part of R^2 comes from the between effect, whereas the within effect (fixed effect) only accounts for a small part the explanation. The overall model fit, R^2, (r2 for OLS_2003 and OLS_cluster, r2_o for FE and RE) is quite small for all regressions (0.01-0.24) despite the rich data set in this study.

As concluded in the econometric approach section and illustrated in table 5, estimating a FE model will only provide estimates for a very limited number of the variables of interest. 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 estimating RE models.

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 also found in earlier papers (see appendix 1). 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 use significantly less natural gas than houses constructed earlier.

Table 4 suggested several differences between the subsamples of the panel data set defined by construction periods. Earlier papers have not explored the possibility of allowing different effects of e.g. house size and other characteristics on energy demand in relation to construction periods. In table 6 we continue exploring the dataset by estimating RE models on each of the 8 sub samples, and compare the parameter estimates for each period with the estimations from RE model for the total dataset.

Table 6 Regression coefficients for RE models of the total panel (RE) and the subsamples defined by vintage classes

Dependent variable= logarithm of annual household natural gas consumption (lngas)									
	RE	RE_1930	RE_1950	RE_1960	RE_1972	RE_1978	RE_1985	RE_1998	RE_2002
Degree-day	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***
Lnhouse-size	0.5073***	0.5464***	0.4972***	0.4048***	0.4904***	0.5726***	0.5437***	0.7785***	0.5746***
Lndispinc	0.0207***	0.0257**	0.0217**	0.0191*	0.0199***	0.0155**	0.0267*	0.0153	0.0527*
Vintage<30	0.0034	-	-	-	-	-	-	-	-
Vintage31-50	0.0250**	-	-	-	-	-	-	-	-
Vintage61-72	-0.0968***	-	-	-	-	-	-	-	-
Vintage73-78	-0.2102***	-	-	-	-	-	-	-	-
Vintage79-85	-0.3420***	-	-	-	-	-	-	-	-
Vintage86-98	-0.3667***	-	-	-	-	-	-	-	-
Vintage99-02	-0.4385***	-	-	-	-	-	-	-	-
HNG	0.0772***	0.2144***	0.1371***	0.0541**	0.0847***	0.0415***	-0.0202	-0.0269	-0.0383
Boiler age<10	-0.0076**	-0.0004	-0.0038	-0.0127	-0.0086*	-0.0073	-0.0187	-0.0165	0.1393
YSB<11	-0.0054	-0.0061	-0.0025	-0.0115	-0.0097*	-0.0014	-0.0028	-0.0016	-0.0826
D_retro<=70	0.0225*	0.0157	0.0027	0.0121	-0.0007	-	-	-	-
D_retro71-80	-0.0239***	-0.0408*	-0.0569**	-0.0406**	-0.0120	-0.0100	0.1143	-	-
D_retro81-90	-0.0713***	-0.1028***	-0.1068***	-0.1075***	-0.0491***	-0.0628***	-0.0050	-0.0998	-
D_retro>=91	-0.0940***	-0.0786***	-0.1332***	-0.1430***	-0.0896***	-0.0264	-0.0557*	-0.1092***	-0.1681
Age<=20	0.0780***	0.0460	0.0822**	0.0863**	0.0923***	0.0485	0.0981*	0.1116	0.1537
Age31-40	0.0068	0.0130	0.0144	0.0249	0.0115	-0.0388	-0.0244	0.0152	0.0148
Age41-50	0.0207*	0.0288	0.0022	0.0520*	0.0255	-0.0015	-0.0026	0.0198	0.0666
Age51-60	0.0093	0.0090	0.0229	0.0497*	0.0079	0.0085	-0.0387	-0.0295	0.0210
Age61-70	0.0455***	0.0233	0.0741**	0.0405	0.0643***	0.0445	-0.0660	0.0080	-0.0155
Age>=71	0.1117***	0.1623***	0.0563	0.1510***	0.1258***	0.0586*	0.0320	0.0724	0.1160
Lnpers	0.0315***	0.0023	0.0297	0.0390*	0.0341**	0.0224	0.0581*	0.0871**	0.0281
Time trend	-0.0094***	-0.0083***	-0.0050**	-0.0082***	-0.0116***	-0.0097***	-0.0082***	-0.0088***	-0.0368***
D_elab1	-0.0825***	-0.0762***	-0.0841***	-0.0892***	-0.0825***	-0.0976***	-0.0558*	-0.0568**	0.0084
_cons	6.8924***	6.5539***	6.8501***	7.4203***	6.8688***	6.4294***	6.4129***	5.2674***	5.6568***
N	150.552	18.252	17.896	19.359	55.678	23.069	7.688	7.835	775
r2_o	0.2296	0.2043	0.2028	0.2066	0.1873	0.1696	0.1700	0.2306	0.1792
r2_b	0.2477	0.2517	0.2218	0.2172	0.1877	0.1621	0.1827	0.2646	0.1927
r2_w	0.0542	0.0280	0.0481	0.0617	0.0715	0.0642	0.0529	0.0776	0.1637

Note: ***: significance at 1%, **: significance at 5% and *: significance at 10%

Note: RE is the Random Effect model for the total panel, RE_1930 is the RE model for the sub group of houses constructed before 1930, RE_1950 is houses constructed between 1931-1950, RE_1960 is houses constructed between 1951-1960, RE_1972 is

houses constructed between 1961-1972, RE_1985 is houses constructed between 19973-1985.
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 dummies describing sources of supplementary heating, a set of dummy variables describing number of toilets, a set of dummy variables describing number of bathrooms 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 1951-1960, that has not been retrofitted. The house has one toilet and one bathroom; there are no supplementary heating sources.

The regression coefficients presented in table 6, RE estimations on the 8 sub samples, suggest significant positive signs on the house size variable (estimates range from 0.41-0.78), i.e. the larger the house the more natural gas used. The estimated coefficients for household disposable income are also significantly positive (estimates range from 0.02-0.05), i.e. the higher disposable income the higher demand for natural gas. Further the estimated coefficients suggest significant positive, though very small, coefficients on degree days (estimates = 0.0002), i.e. more degree days (more cold days) increase household natural gas consumption. These results confirm earlier findings listed in appendix 1and the estimated coefficients in table 5.

The majority of the subsample estimations in table 6 confirm that, everything else being equal, houses situated in the HNG area use more natural gas than the MN houses. This confirms the picture from figure 3. When looking at the variables describing whether and when the house has been retrofitted, we find significant estimates reveling that the time of retrofitting matters to household natural gas consumption. Compared to non-retrofitted houses, houses retrofitted 1971-1980 use less natural gas, and more recent retrofitted houses use even less natural gas.

Again we find significant negative signs on the energy label dummy (*D_elab1*) in all four estimations. It contradicts the findings in Kjaerbye (2008). However in Kjaerbye 2008 the focus was on estimating the effect of the labeling and hence comparing energy consumption with the most suitable control group of houses; so we believe more in Kjaerbye (2008) than the results here. A potential explanation of the result here is that it is an indication of an overall positive environmental behavior and not the labeling as an independent intervention (policy instrument).

As in table 5, we present overall R^2 (r2_o), R^2 between (r2_b) and R^2 within (r2_w). The results show that the largest part of R^2 comes from the between effect, whereas the within effect (fixed effect) only accounts for a small part the explanation. The overall model fit (r2_o) is quite small for all regressions (0.17-0.23), but at the level of R^2 presented in the papers referred to in appendix 1. These small R^2 indicates that household natural gas consumption depends largely on unobservable variables. Several papers have identified that habits and norms plays a great role in household energy demand. Such information has not been possible to include in the estimations performed in this paper.

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 1pct. level) parameter estimates from table 5. The same house/household specification is used for all construction periods. The only difference is therefore the construction of the house (insulation, windows and other unobserved characteristics). The standard house is described using mean values of 2003 cross section data set. The house is 145 m^2 and it is situated in the HNG area. Disposable household income is 52868 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 4 shows the predicted amount of natural gas (kWh/m^2) used in the specified standard house. The dotted vertical lines refer to limits between the defined vintage groups, and for the later periods they also represents years of changes in BR.

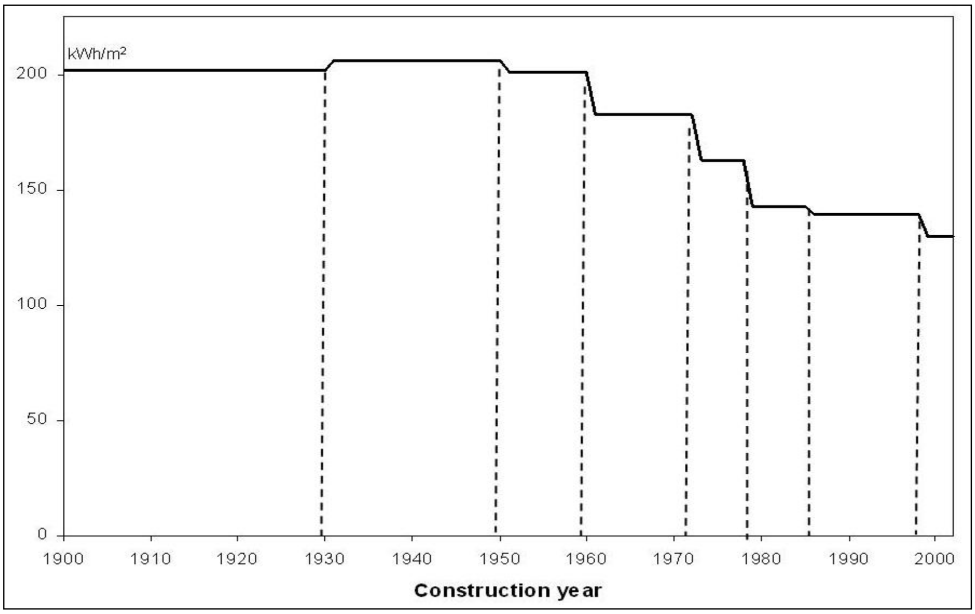

Figure 4 Estimated household natural gas consumption kWh/m^2 per year calculated for a comparable standard house constructed in different periods

Figure 4 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 follows what was found in the study of Leth-Petersen (2002), who 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 7 presents this ex post estimation.

Table 7 Estimated changes in household natural gas consumption due to changes in building regulations

	Vintage classes -1930	1931-50	1951-60	1961-72	1973-78	1979-85	1986-98	1999-02
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/m2		4	-5	-19	-20	-20	-3	-10
Difference from prior period, pct.		2%	-2%	-9%	-11%	-12%	-2%	-7%
Total national m^2 of constructed single-family during period (1000 m2)	37,977	16,822	11,981	8,458	20,423	9,582	6,872	3,309

Source: Statistics Denmark, 2009 and own calculations

The estimated amounts of household natural gas consumption (kWh/m^2) are used in table 7 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 pct. when comparing houses constructed in the period before 1999 and houses constructed in 1999-2002.

10 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.

There is no question that stricter building regulations over time lead to a more energy efficient house stock. But on 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 en 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 is thought of as a combination of policy instruments (regulatory instruments, information instruments, financial/fiscal incentives and voluntary agreements) 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.

Finally it should not be forgotten that tightening of building requirement is not by nature more efficient in a global warming perspective than investments in renewable energy production on site (e.g. photovoltaic and solar water heater) or district heating produced off site and based on renewable fuels (e.g. biomass).

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13 Appendix 1. Relevant papers and findings

Characteristics	Parameter relationship with energy/space heating demand	Reference	R^2 HAD EXAMINED IN THE NOVEMBER 1 TO BREAK YESTERDAY IN
House characteristics			
House size	Positive	Nesbakken 1999 (cross section)	
		Rehdanz 2007 (cross section)	0.173-0.269
		Sardianou 2008 (cross section)	0.205-0.37
		Santin et al.2009	0.38-0.42
	Positive – but also positive correlation between house size and income and family size	Scott 1980	0.357-0.422
Vintage	Space heating increases with house age – newer houses are better insulated and use less energy for heating	Leth-Petersen 2002 (cross section)	
		Leth-Petersen and Togeby 2001 (panel data)	0.322
		Nesbakken 2001	
		Rehdanz 2007 (cross section)	0.173-0.269
		Santin et al.2009	0.38-0.42
Insulation	Floor insulation, double glazing and crawl space are found to reduce consumption of gas	Berkhout et al. 2004 (panel data)	0.4
Household characteristics			
Household income	Positive- space heating increases with increased income	Baker et al 1989	0.339 - 0.412
		Bernard et al 1996	
		Biesiot and Noorman 1999	
		Capper and Scott 1982	
		Dubin et al 1986	
		Garbacz 1983	
		Hirst et al 1982	
		Klein 1987	
		Meier and Rehdanz 2008	0.264-0.301
		Nesbakken 1999 (cross section)	
		Nesbakken 2001	
		Rehdanz 2007	0.173-0.269
		Poyer and Williams 1993	
		Santin et al.2009	0.38-0.42

		Sardianou 2008 (cross section)	0.205-0.37
		Schuler et al. 2000 (cross section)	0.117-0.149
		Vringer 2005	
Age	Positive – elderly prefer higher room temperature	Liao and Chang 2002	
		Lindén et al. 2006	
		Meier and Rehdanz 2008	0.264-0.301
		Nesbakken 1999 and 2001	
		Rehdanz 2007	0.173-0.269
		Santin et al.2009	0.38-0.42
		Sardianou 2008 (cross section)	0.205-0.37
		Tonn and Eisenberg 2007	
		Vaage 2000	
		Yamasaki and Tominaga 1997	
Household size	Positive	Berkhout et al. 2004 (panel data)	0.4
		Meier and Rehdanz 2008	0.264-0.301
	Negative – increasing number of household members decreases fuel consumption per capita	Sardianou 2008 (cross section)	0.205-0.37
Household composition:			
Existence of retired person	Negative	Meier and Rehdanz 2008	0.264-0.301
Number of children	Positive if children <5 years	Baker et al 1989	0.169-0.398
	Positive – existence of a baby increases space heating	Capper and Scott 1982	0.339 - 0.412
	Positive – number of children increases heating expenditure	Hirst et al 1982	
		Meier and Rehdanz 2008	0.264-0.301
	Positive – existence of child <16 years increase energy cons.	Nesbakken 1999 (cross section)	
	Negative	Rehdanz 2007 (cross section)	0.173-0.269
Behaviour – preferences in space heating	e.g. no clear relation between energy use for space heating and the thermal characteristics of a building, but linear relation between energy demand for space heating and indoor temperature	Haas et al. 1998	
		Lindén et al. 2006	

Number of showers	Average number of showers a week is positive correlated with gas consumption	Berkhout et al. 2004 (panel data)	0.4
Someone home during day	One family member home during the day has positive effect on gas consumption	Berkhout et al. 2004 (panel data)	0.4
<u>Other:</u>			
Oil price	Negative – increase in oil price decreases fuel consumption	Dubin et al (1986)	
		Isaskson 1983	
		Sardianou 2008 (cross section)	0.205-0.37
		Scott 1980	0.357-0.422
Weather condition (degree days)	Positive	Leth-Petersen and Togeby 2001 (panel data)	0.322
		Nesbakken 1999 (cross section)	
		Strout 1961	