Universität Stuttgart
Institut für Energiewirtschaft und Rationelle Energieanwendung IER

Forschungsbericht

# Effective Policy Instruments for Energy Efficiency in Residential Space Heating – an International Empirical Analysis (EPISODE)

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***IER*** in cooperation with:

ADEME, Sophia Antipolis, France

AKF, Copenhagen, Denmark

NW&S, Utrecht University, The Netherlands

BPhys, Lund University, Sweden

Band 71

# Effective Policy Instruments for Energy Efficiency in Residential Space Heating – an International Empirical Analysis (EPISODE)

Research funded in part by
**The European Commission**
in the framework of the
Non Nuclear Energy Programme
**JOULE III**
**Contract JOS3-CT97-0014**
**01/01/98 to 31/12/99**

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June 2000

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NW&S, Utrecht University, The Netherlands

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**ISSN 0938-1228**

## Foreword

This study has been supported by the European Commission, DG XII within the JOULE programme under contract No. JOS3-CT97-0014. This funding from the European Commission and of national co-financing institutions is gratefully acknowledged. The project has been carried out jointly by the Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Germany (co-ordinator), the French Environment and Energy Agency (ADEME), Sophia Antipolis, the Danish Institute for Local Government Studies (AKF), Copenhagen, the Department of Science, Technology and Society (NW&S), Utrecht University, The Netherlands and the Department of Building Physics (BPhys), Lund University, Sweden. Besides this common final report a series of working papers has been written within the project, which give more details on the different aspects of the topics summarised in this final report. These working papers are available at the internet site www.ier.uni-stuttgart.de/episode and have also been compiled in a material volume:

> C. Schaefer, C. Weber, H. Voss-Uhlenbrock, A. Schuler, F. Oosterhuis, E. Nieuwlaar, R. Angioletti, E. Kjellsson, S. Leth-Petersen, M. Togeby, J. Munksgaard:
> Materials on Instruments for Energy Efficiency in Residential Space Heating.
> Stuttgart et. al., 2000

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# Abstract

A broad variety of instruments like standards, taxes, subsidies and informational campaigns is used in Europe to influence the energy consumption for residential space heating. Within the project EPISODE the existing instruments in countries in the northern and moderate climatic zones have been analysed with a focus on The Netherlands, France, Denmark, Sweden and Germany have been analysed. In these countries space heating accounts for about 70% of the residential energy consumption. The effectiveness of the applied instruments has been analysed by an international empirical analysis based on survey data. Additionally the results of the empirical analysis have been compared with the results of a building simulation model in order to confirm or negate the empirical results. The analysed instruments lead to a decrease in energy consumption per square meter dwelling area. Especially standards have shown a strong influence on the energy reduction in the past. The analysis has also shown that the influence of taxes is very small in the short-term. A comparison of the energy consumption for space heating between the participating countries has also shown that there is still a considerable potential for energy savings. Future policies in the field should combine a bundle of instruments to achieve substantial emission reductions at low costs. Emission taxes as economically efficient instrument play thereby an important role, but also flexible standards are important for new dwellings. Subsidies and informational measures are particular important to activate energy efficiency potentials in the existing building stock.

# 0 Executive Summary

## 0.1 Introduction

Energy consumption for space heating accounts in northern and moderate climatic zones for the major share of residential energy consumption. Large potentials for energy saving and emission abatement have been identified in the past in this field. Consequently the member states of the European Union have implemented a broad variety of instruments - standards, taxes, subsidies - aiming at the realisation of these potentials. Without doubt, these resulted in decreasing energy consumption and emissions per square meter dwelling area. However, further tightening of the measures is required to meet new environmental objectives such as the emission reduction goals engaged by the European Union at the Kyoto conference.

In this context the main research objectives of the project "Effective policy instruments for energy efficiency in residential space heating – an empirical analysis" (EPISODE) have been:

- Interdisciplinary comparison of existing policy instruments for energy efficiency in the field of space heating on a theoretical basis accounting for economic, technical and political considerations.
- Empirical assessment of the effectiveness of the different instruments based on sample surveys to confirm or refute the theoretical considerations. In particular an in-depth analysis whether stipulated technical standards are met properly.
- Recommendations for further regulations drawn from the theoretical and empirical analysis of existing instruments.

## 0.2 Existing policies for energy efficiency in space heating

An overview of key figures for energy use in the residential sector shows the important role of residential space heating in the participating countries. Space heating accounts in most countries for around 70 % of the total residential energy demand. This corresponds to a share of 15 % to 22 % of the total final energy consumption.

Correspondingly considerable efforts have already been devoted in the past in the countries under study to increase energy efficiency in space heating. These policies have been embedded in the general energy and environmental policies of the countries. For all examined countries the traditional national objectives of energy policy (safety, security of supply) have been supplemented in the last years by environmental goals motivated mostly by the threat of global warming. Additionally to this Europe- (and world-)wide environmental objective there exist specific targets for the residential sector within some countries. Sweden aims to reduce the use of electricity for space heating, the Netherlands wants to increase the energy effciency of the residential sector by more than 2 % per year and Denmark still tries to promote its district heating system.

At least for a medium time range (up to ten years) regulatory policy has to account for binding restrictions stemming from the existing energy system, the dwelling stock, the techniques used or external market conditions. These restrictions vary considerably within the countries under study and it should be emphasised that there are not only restrictions but also potentials.

In this context all countries examined aim at least at a further decline in unit consumption of energy for space heating, if not a decrease in overall consumption. The following types of measures are already under use to reach this objective:

- Standards for new and renovated buildings as well as heating systems,
- Fuel/energy taxes,
- Subsidies,
- Information, consultancy and labelling schemes.

Similarities and differences of the observed instruments can be summarised as follows:

- *Standards:* Despite the lack of a harmonised European policy some convergence in the national use of standards is found concerning the strength of requirements for heating energy conservation as well as their scope. Every country takes another key value of the building system to establish national limit values. Therefrom difficulties for a direct comparison of the strength of regulation result.
- *Taxes:* Regarding their considerable revenues, taxes are probably the main instrument beside the standards because a step by step widening and deepening of the tax base and rates happened in the nineties.
- *Subsidies:* In comparison to the step by step tightening of standards and taxes, subsidy schemes are launched for specific goals and only for a limited period. All over the countries examined they are mainly used to strengthen retrofitting activities in the old building stock and to promote renewable energies.
- *Other instruments:* Screening the national information activities it can be seen that there is no regular institutionalised information policy for energy efficiency in residential space heating. Consultancy and audits concerning energy consumption for space heating have become important in some countries, e. g., in Denmark the mandatory energy label for buildings which are to be sold.

## 0.3 Modelling the energy consumption for space heating and the impact of policy instruments

How do policy instruments such as standards, taxes and subsidies influence the energy demand for residential space heating? This is the main research question addressed by the

EPISODE project. It links elements of the policy sphere, i. e. policy instruments, to elements of the engineering / natural science sphere, i. e. energy demand and energy efficiency.

The most straightforward but theoretically least satisfying way to establish the linkage between policy instruments and residential space heating demand is to assume a black box with policy instruments as inputs and observed energy consumption as output. Thus the first aim of this section is to develop in detail a causal model which prevents from just data mining. However, data availability restrictions make further modifications of the model for the empirical application unavoidable. Therefore the second aim of this section is to present a scheme of analysis for the empirical investigations on the basis of a careful compromise between actual data availability and the demand of the theoretical causal model.

Going from theoretical considerations to empirically applicable models the following steps of analysis are undertaken:

- At given building characteristics and at given climate, the energy consumption for space heating can be described on the one hand by technical relationships and on the other hand by the utilisation patterns of the occupants of the building.
- From these relationships a building model is derived that may be used for technical simulations
- A further possibility is to derive a regression model from the technical relations. Such a model is derived with a focus on the building shell, as opposed to a focus on the heating system in much of the earlier work.
- An important point to account for is that the building characteristics are influenced by investment decisions, e. g. investment in capital goods such as a new boiler or an improved insulation. Therefore investment variables (which may be monetary or physical ones) enter the technical model developed previously and have in turn to be explained by some kind of investment model.
- Policy instruments then influence the investment decision in energy saving capital goods and they may also influence the actual production of space heat at given building state.
- For an adequate empirical analysis appropriate econometric techniques have to be employed. Here the use of panel estimation techniques is proposed

## 0.4 Empirical results

For the empirical statistical analyses comprehensive data were needed containing information about the energy demand of the building, the building type, the vintage class of the building, the vintage class of the boiler, the type of heating system, the type of energy carrier, the dwelling space and further information concerning the occupant characteristics. For most countries data bases covering several observation years were available

The effects analysed in the empirical investigations can be summarised as follows:

- *Vintage class effects:* A reduction of the specific energy demand for space heating has been observed in all participating countries for buildings built since the 1970s. This reduction was mainly caused by the introduction and tightening of energy efficiency standards. The observed influence of the vintage class / standards is very strong.
- *Building types:* Per square meter of dwelling space attached houses use less energy than detached houses. Apartments in multi-family houses have an even lower specific consumption.
- *Energy carrier / heating system:* The following energy carriers have been analysed: Oil, gas, district heat, electricity and wood (additional use). A low energy demand is observed in general for buildings using district heat or electricity. For oil, gas and wood the results depend on national specificities and are only partly comparable.
- *Retrofit / renovation:* The impact of retrofit measures like insulation of windows, wall insulation, thermostats and major reconstruction of dwellings has been investigated. The empirical results show that the retrofit measures reduce the energy demand, but considerable differences occur between countries. Compared to the impact of the vintage classes or the used energy carrier / heating system, the influence of retrofit measures is in general small.
- *Other building characteristics:* A decrease of the specific energy demand is observed when the dwelling space or the number of flats / floors increases. This can be explained, like for the building types, by decreases in the surface-to-volume ration and thus reduced heat losses.
- *Owner types:* Several owner types have been analysed but the influence of all estimated coefficients is small and the national findings are rather different.
- *Occupant characteristics:* To characterise the persons, who live in the dwelling. information about their income, the age and the employment has been used. The observed influences on the energy demand are often significant albeit small. Notably elderly people in general use more energy for space heating.
- *Price and tax effects:* The analysed influences of the price of oil, gas, district heat and electricity indicate also the probable impact of energy taxes in the short run. The observed influence is rather small, if it is significantly negative at all.
- *Subsidies and other instruments:* Instruments like the Danish heat audit and the energy test reduce the energy demand of a building. This influence has been confirmed by the empirical results. Also for Germany the number of available subsidies has been shown to have a significant negative impact on energy use at least for single-family-houses. However the empirical results show that the influence of these measures is small.

- *Time trend:* The influence of the time trend, which captures in particular the impact of not explicitly modelled efficiency improvements, is in general negative, although the influence is very small.
- *Climatic and regional characteristics:* The influence of climatic zones is strong in countries like France and Sweden with large climatic variations within the country.

The influence of vintage classes (standards) has been also analysed with the building model, based on technical aspects like the building geometry, U-values, efficiency of the heating system and climatic data. Varying the U-values for different vintage classes confirms the strong influence of building codes. Even the technically simulated impact is higher than the empirically observed one. Furthermore the effectiveness of the different national building codes has been compared with the help of the building model, using different U-values and constant climatic and geometric data. The results show a low energy demand especially in the Scandinavian countries.

## 0.5 Assessment of policy instruments

Based on the empirical investigations and further theoretical considerations the policy instruments are assessed. The major findings are:

*Standards:* The empirical results have shown that standards are an effective instrument to reduce the specific heating energy demand for new buildings in all participating countries. The comparison of empirical results and calculated results has shown differences which are due to imperfect application of standards and the rebound effect.

All analysed standards aim at new buildings. For existing buildings standards do not exist at this point. Both types of standards could be effective but there are doubts on the efficiency of both. In the Netherlands investigations have shown that a further tightening of standards will be increasingly costly. A uniform European standard would be problematic due to the international differences concerning the climate and buildingstyles but a harmonisation of the different international calculation methods would be helpful. Not only the building shell should be treated in the standards, the heating system should be integrated because the energy efficiency of the building depends on both

*Taxes:* Until the mid-nineties taxes have played a minor role as policy instruments to reduce the energy demand for space heating in the participating countries except Denmark. Taxes can influence the energy demand in the short term by changing the heating and airing behaviour of the occupants and in the long term by influencing the investment decision concerning insulation measures and energy efficient equipment. The short term influence of taxes has been found to be rather limited according to the empirical investigations. Due to the available data it was not possible to analyse the impact of taxes on the energy demand in the long run.

Taxes are known as a efficient instrument in the theory, but in the reality barriers exist which lower the efficiency of taxes: Incomplete information, not fully rational behaviour and principal-agent problems. If the reduction of greenhouse gas emissions is the primary objective of the taxation the tax rates should be based on the carbon content of fuels.

*Subsidies:* One advantage of subsidy schemes is that the schemes can work as well for existing buildings as for new buildings. In all countries only a small number of subsidy schemes exist except Germany where a lot of subsidy schemes are provided by federal, regional or local institutions. The empirical investigations have shown a small influence of subsidies. In The Netherlands the theoretical savings appear to exceed the observed savings of insulation measures promoted by subsidies. These differences may be caused by rebound effects. Furthermore "free rider"-effects often occur with subsidies, reducing further their effectiveness.

*Other instruments:* The empirical analyses reveal that other, in particular informational instruments have only a limited impact on energy efficiency. E. g. the Danish consultancy schemes like the "heat audit" and the "energy test" have small measurable effects, but these schemes often are additional instruments working together with subsidies for example.

Individual metering is also an important instrument aiming at the behaviour of the occupants, which then have to pay only for the energy they have used themselves. So saving of energy costs is linked to a reduction of the energy demand of each customer.

Labelling as done in Denmark when houses are going to be sold provides information about the energy efficiency of the building to the investor. Mandatory labelling could also be interesting for equipment like boilers, increasing also the competition between manufacturers aiming at the most efficient product.

## 0.6 Conclusions

The following recommendations for EU and national policies can be formulated:

- Apply carbon taxes, but do not expect them to have a large impact in the short run.
- Allow flexibility in standards for new buildings.
- Look especially for energy savings in existing buildings.
- Address specific barriers to energy savings in the existing building stock by means of appropriate supplementary instruments.
- Design policy instruments so as to improve implementation and to reduce the "rebound effect".
- Introduce some harmonisation at the EU level, but do not aim at completely uniform EU wide standards.
- Maximise flexibility in energy supply systems for new housing projects.

- Compare the costs of energy saving in residential space heating with those in other areas.
- Do not get discouraged by the limitations of the influence of energy policies on residential heating energy use.

# 1 Introduction

Energy consumption for space heating accounts in northern and moderate climatic zones for the major share of residential energy consumption. Large potentials for energy saving and emission abatement have been identified in the past in this field. Consequently the member states of the European Union have implemented a broad variety of instruments - standards, taxes, subsidies - aiming at the realisation of these potentials. Without doubt, these resulted in decreasing energy consumption and emissions per square meter dwelling area. However, further tightening of the measures is required to meet new environmental objectives such as the emission reduction goals engaged by the European Union at the Kyoto conference.

So far yet the actual effect of standards, subsidies and taxes is often not known but only roughly estimated. Besides, the variety of instruments applied constitutes an impediment to the European internal market since producers of energy efficient equipment (insulation, heating systems), building enterprises and architects have to comply with varying legislation in the member states. Therefore a need for harmonisation in the future arises. Additionally, there are also serious doubts on the efficiency of the existing instruments.

Therefore the project "Effective Policy Instruments for Energy Efficiency in Residential Space Heating – An International Empirical Analysis" (EPISODE) has aimed at a detailed analysis of the factors influencing the energy efficiency of dwellings in view of the development of improved and harmonised regulations. The approach is based on the empirical analysis of the effects of existing policy instruments in different member states, such as standards, taxes and subsidies on insulation technologies and heating system technologies. This is done by using existing survey data to account not solely for theoretical considerations - stemming from economic analysis and technical simulation models - but also for practical aspects such as information problems or incomplete application. Thus the main research objectives of the project may be summarised as follows:

- Interdisciplinary comparison of existing policy instruments for energy efficiency in the field of space heating on a theoretical basis accounting for economic, technical and political considerations.
- Empirical assessment of the effectiveness of the different instruments based on sample surveys to confirm or refute the theoretical considerations. In particular an in-depth analysis whether stipulated technical standards are met properly.
- Recommendations for further regulations drawn from the theoretical and empirical analysis of existing instruments.

The results of the research hence provide an input to the development of effective strategies for energy efficiency and climate change mitigation in the field of space heating at European, national and regional level. Therefore recommendations for future harmonised strategies in this field are derived which account for the environmental objectives of the European Union but also for further policy concerns such as the principle of subsidiarity and the perfection of the European internal market.

The next chapter of the present report gives an overview over the existing policy instruments in the participating countries aiming at energy efficiency in space heating. The third chapter sketches the techno-economic model and the econometric techniques which are used as a basis for the empirical analysis. The fourth chapter describes the results of the empirical analyses based on the techno-economic model presented in the previous chapter and a comparison of the international results which shows differences and similarities. The fourth chapter also presents the results of the building model which calculates the energy demand for space heating with the help of technical aspects like the building geometry and U-values and additionally with climatic data. The fourth chapter ends with a comparison of empirical results and the calculated results of the building model. In the fifth chapter the existing policies are assessed in view of the empirical results and further theoretical considerations. Finally conclusions and recommendations for future policies and instruments are summarised in the last chapter.

# 2 Existing policies for energy efficiency in space heating

In order to derive sound recommendations for future policies in the field of residential space heating, first the existing policy instruments should be reviewed carefully. In the following this is done focusing on the countries of the project partners, namely The Netherlands, France, Denmark, Sweden and Germany[1]. In these countries a broad variety of policy instruments is found and only where appropriate examples from other countries are considered. First the background of regulation in the examined countries is presented in section 2.1. The current situation with respect to the energy consumption for residential space heating is described. In section 2.2 political priorities and objectives in the field of residential energy use are discussed. The subsequent sections deal with the different types of instruments encountered, starting with standards as the traditionally predominant policy instrument (section 2.3). Taxes as instrument which has gained importance in the last years are dealt with in section 2.4. Subsidies are reviewed in section 2.5 whereas the other instruments of subordinated importance are summarised in section 2.6.

## 2.1 Energy consumption in residential space heating

In all countries examined, the energy consumption for space heating plays an important role (cf. Table 2-1). From 14.8% in Sweden up to 22.6 % in France of the total final energy consumption were used for residential space heating. The numbers vary considerably between the Netherlands and the other countries which are more or less around 20%. Compared to total residential energy consumption space heating accounts in most countries for around 70%.

An important indicator for heating energy use is the unit consumption, i.e. the consumption of energy for space heating per $m^2$. Denmark and Sweden show the lowest unit consumption when comparing the five countries, France show the highest number per $m^2$ in 1995.

Also, per capita numbers are calculated for further comparison of the consumption figures concerning residential space heating. Due to the lowest average dwelling space per capita in the Netherlands, only 5.7 MWh per capita are consumed, whereas in Denmark 7.1 MWh per capita are used. However, if one takes climatic conditions into consideration, i.e.,

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[1] The other EU countries in the northern or moderate climatic zones being Austria, Belgium, Finland, Ireland, Luxemburg and United Kingdom have also been reviewed within the EPISODE project. The corresponding results can be found in the working papers /Kjellsson 1998b/, /Oosterhuis, Nieuwlaar 1998b/, /Oosterhuis, Nieuwlaar 1998c/, /Schuler et al. 1998c/ and /Schuler et al. 1998d/.

**Table 2-1:** Key figures for residential space heating consumption in the countries examined in 1995

| | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **(1) Energy consumption residential sector (TWh)** | 52.82 | 485.7 | 716.1 | 129.1 | 92 |
| **(2) Energy for residential space heating (TWh)** | 36.7 | 372.5 | 548.2 | 87.5 | 58 |
| **Energy for residential space heating per capita MWh/cap** | 7.1 | 6.4 | 6.7 | 5.7 | 6.6 |
| **Energy for residential space heating per capita and per degree day kWh/cap, K*day** | 2.43 | 2.6 | 2.22 | 1.77 | 1.7 |
| **Energy for residential space heating per $m^2$ kWh/$m^2$** | 139 | 189 | 186 | 151 | 126/134* |
| **Energy for residential space heating per $m^2$ and per degree day Wh/($m^2$K*day)** | 48 | 77 | 61 | 46 | 33/35* |
| **Share (2)/(1)** | 69.5 % | 76.7 % | 76.6 % | 67.8% | 61.7% |
| **Share (2)/total final energy consumption** | 21.1 % | 22.6 % | 21.4 % | 15.4 % | 14.8% |
| *one-two family houses/multi-family houses | | | | | |

dividing the per capita consumption by the number of degree days[2], the Swedish and Dutch consumption figures are the lowest when comparing the five countries. In France, during the heating season per capita and per degree day 0.83 kWh more are used compared to the Netherlands, i. e. 47 %, but per $m^2$ and per degree day 31 Wh/$m^2$K more, i. e. 67 %.

Looking at the development of the final consumption for residential space heating reveals also noticeable differences (cf. Table 2-2). First of all the tendencies differ between the countries. Denmark and the Netherlands report declining figures, the consumption level in Sweden remains unchanged, whereas Germany and France present a slight increase in absolute energy consumption for residential space heating (cf. Table 2-2).

[2] This is only a rough calculation because of the differences in calculation methods of degree days.

**Table 2-2:** Development of final energy consumption for residential space heating decomposed in components - total energy consumption, dwelling space, unit consumption

| Index: 1975=100 | 1975 | 1980 | 1985 | 1990 | 1995 |
|---|---|---|---|---|---|
| **Energy consumption** | | | | | |
| **DK** | 100 | 89 | 80 | 74 | 76 |
| **F** | 100 | 95 | 93 | 98 | 102 |
| **D** | 100 | 99 | 105 | 102 | 117 |
| **NL** | *100 | 121 | 113 | 106 | 100 |
| **S** | 100 | 93 | 85 | 88 | 89 |
| **Dwelling Space** | | | | | |
| **DK** | | *100 | 106 | 111 | 115 |
| **F** | 100 | 104 | 107 | 111 | 111 |
| **D** | 100 | 115 | 126 | 137 | 148 |
| **NL** | *100 | 119 | 133 | 141 | 154 |
| **S** | 100 | 110 | 122 | 124 | 134 |
| **Unit consumption** | | | | | |
| **DK** | | *100 | 84 | 74 | 73 |
| **F** | 100 | 88 | 77 | 75 | 73 |
| **D** | 100 | 83 | 77 | 75 | 70 |
| **NL** | *100 | 102 | 85 | 75 | 65 |
| **S** | 100 | 83 | 69 | 71 | 67 |
| The German index is calculated for the former FRG; * NL 1973: 100 and DK 1980: 100 because basis data for 1975 are not available from the national statistics | | | | | |

For a further understanding of these figures the development of the final energy consumption for space heating can be split up in the following components:

- the quantity effect (number of dwellings, increase of dwelling space) and
- the unit consumption effect (average consumption per dwelling space).

The latter effect is influenced by

- the building efficiency;
- the fuel mix and the technology efficiency;
- the level of comfort inside the dwelling (central heating equipment rate) and the behaviour of households, depending among others on their income;
- and the ratio between single-family dwellings and multi-family dwellings (cf. /Bosseboeuf et al. 1997/).

All over the five countries a trend towards increasing dwelling space is reported (cf. dwelling space in Table 2-2)[3]. If this tendency cannot be offset by the reduction of energy consumption per square meter an absolute increase will be observed like in France and Germany. However,

[3] Note that the increase in the dwelling space is partly caused by an increase in the population during this period, e. g. in Sweden from 8.1 mil. in 1970 to 8.8 mil. in 1995, and partly by an increase in dwelling space per capita.

all countries report a strong decrease in unit consumption. Sweden reports a strong effect due to changes in fuel mix, especially the replacement of oil heating by electric or district heating, which is more efficient at the final energy level /Kjellsson 1998a/. However in general, for the future development it is crucial to consider both, the increase in dwelling space demand as well as the rate of technical development concerning the building and heating system.

## 2.2 Energy priorities and policy targets

For all examined countries the traditional national objectives of energy policy (safety, security of supply) have been supplemented in the last years by environmental goals motivated mostly by the threat of global warming. E. g., most of the countries examined are referring directly to a reduction of $CO_2$ (cf. Table 2-3). Existing objectives concerning the substitution of finite resources like oil are renewed under the vision of sustainable development. Given the mentioned large share of residential space heating in total energy consumption in all countries (cf. section 2.1), also particular policy statements concerning residential space heating exist (cf. Table 2-3).

For Denmark concrete targets are mentioned in the energy action plan from 1996. Reduction targets for $CO_2$ and $SO_2$ are fixed as well as targets for energy efficiency improvements and the use of renewable energy carriers. Goals for residential space heating are strongly influenced by the further strengthening of district heating. An overall energy efficiency goal is of most importance in the Netherlands, too. Per year the energy efficiency should be improved by 2 %. Target figures for the residential sector exceed this average value. In Germany the situation is characterised by the reduction goal of $CO_2$ stemming from the early nineties. Based on this mainly the revision of the specific decrees influencing residential space heating are supported. In France environmental preoccupation was strengthened during the 90ties caused by an on-going ecological debate whereas demand side policies of the 80ties and early 90ties were phased out and not renewed. In Sweden during 1997 a decision on phasing out of nuclear power was taken. Therefore the whole energy policy and the special efficiency goals for residential space heating are aiming at a conversion from the use of electricity for heating to using other fuels (except oil), or especially district heating.

Regulatory policy has to keep in mind binding restrictions for measures which would be undertaken within a medium time range (up to ten years). These restrictions may stem from the existing energy system, the dwelling structure, techniques used or external market conditions. However, there are potentials, too[4]. The following points are remarkable:

- Energy system: For energy carrier substitution the case of the Netherlands shows a strong restriction because of the strong dependency on gas. Potentials are often seen in

[4] Cf. the discussion of restrictions and potentials as found in urban planning theory, e. g. /Friedmann 1986/.

a larger share of district heating in Germany and France. France will also have to manage a high increase of electricity consumption and renewal of old nuclear plants which is predicted for 2010. This preoccupation could introduce larger DSM measures on electricity use which may also induce some further substitution from electric heating to other fuels.

- Dwelling structure: With a very small new construction market the Swedish possibilities to improve energy efficiency are mostly restricted to retrofitting activities. Potentials to use in the midterm are connected with the possible implementation of low-energy standards for new construction of buildings.
- Techniques: The speed and scope of efficiency improvements e.g., in the case of boiler technologies is slowing down as mentioned for the Netherlands in /Oosterhuis, Nieuwlaar 1998a/. Like in Denmark, the use of alternative sources of energy in the energy conversion sector is seen as a potential.
- Market signals: Low energy prices for oil on the world market make particular efforts necessary if fuel substitution goals are to be defined.

The policy instruments for energy efficiency in residential space heating presented within the next chapters were highly influenced by these policy targets and the presented demographic, climatic and energy context data and information for residential space heating.

**Table 2-3:** Current policy targets in the countries examined

| | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **Environmental goals** | The major targets are<br>- 20 % reduction of emission in 2005 compared with 1988<br>- 60 % reduction of $SO_2$ over the same period.<br>The energy action plan from 1996 stated that<br>- in 2005 the energy intensity will be improved by 20 % on the 1994 level,<br>- renewable energy will be expanded to 12-14 % of the estimated energy consumption of 2005 | Since 1990 energetic preoccupations have less priority and French government reduced DSM policies (caused by price reductions).<br>Environmental preoccupations are, however, strengthening.<br>New energy policies have been announced for 1999 by the Government | The major target is to reduce $CO_2$ emissions until 2005 by 25 % compared to 1990.<br>Under the new government phasing out of nuclear power has become a major policy goal. | Energy efficiency improvement: 25 % over the period 1989/90-2000, since 1993 reduced to 23 %.<br>Actually the general objective from 1998 is an efficiency improvement of 2% per year. | Reduce environmental impact from the energy system, reduce $NO_x$, $CO_2$, $SO_2$ emissions. In 1997 started the phasing out of nuclear power. |
| | Burden Sharing EU greenhouse gases reduction in the period 2008 -12 compared to 1990: whole EU - 8 % -<br>DK - 21.5 % | F - 0 % | D - 21.0 % | NL - 6.0 % | S + 4.0 % |
| **Residential heating energy efficiency goals** | - Support for installation of central heating, systems based on renewable energy and for energy-conservation measures in the existing housing stock<br>- In areas with natural gas or district heating it is not allowed to install electric heating | - Support DSM measures (i. e. information cam-paigns, definition of standards, decision making and financial incentives for existing buildings)<br>- To elaborate new standards there are R&D actions for innovative technologies, calculation tools and methodologies | Different policy actions to influence space heating demand (amendment of decrees, information campaigns, programs to modernize dwellings) | Target figures for the energy efficiency improvements in the residential sector are now above the average of 2 % per year | Energy policy concerning space heating mainly focuses on reducing the use of oil and electricity. In order to decrease the use of electricity for heating new subsidies have been proposed as well as subsidies for alternative production of electricity |
| **Fuel substitution goals** | - Tax rates are still differentiated to turn consumption of energy away from oil.<br>- However, tax rates are harmonised for the main energy carriers toward year 2002. | | Phasing out of nuclear power is a political goal, but timing and substitution goals have not been decided yet. | 10% of total energy supply should come from renewables in 2020 | As there is a decision on phasing out of the nuclear power a conversion from the use of electricity to other fuels (except oil) or district heating has been supported |

## 2.3 Standards

This section presents similarities and differences concerning the mode of operation of building standards within the administrative frameworks of the countries examined. Thus first it deals with the administrative structure and then the calculation methods for coefficients measuring the energy performance of the building system are compared in detail. Basically terms and modes of regulation are rather similar between the countries. In the following mostly methodological differences are presented.

It is quite surprising that despite of few common European regulations in the policy field of building regulations there are so many similarities concerning the level of building decrees. The periods in which the regulations were introduced and later renewed are also quite similar in the countries examined. Table 2-4 shows that in the seventies most of the standards were set off for the first time. After this they were tightened several times.

There are some reasons why thermal insulation development converges from “bottom up” in such a “rhythm of regulation” /Eichhammer, Schlomann 1997/, e. g.

- External events such as the two oil price shocks and the threat of global warming, which were the driving forces behind political campaigning for tighter standards, influenced all countries;
- Technical developments have been available in all countries;
- Research and development has been used in all countries to realise a more efficient use of energy.

In all countries standards are the main instrument for reaching an efficient use of energy in the residential sector. After a twenty years lasting stepwise tightening of standards all examined countries have reached a considerable reduction in energy consumption since the beginning of the regulation. Thus e. g. for France in 1999 a 50% reduction compared with 1975 of the energy performance requirement for new residential construction is reported /Angioletti 1998/ and in Denmark the required maximum heat loss is reduced by 60% when comparing the current building code with the one from 1972 /Leth-Petersen, Togeby 1998 a/.

**Table 2-4:** Administrative structures for setting up standards on building energy efficiency in the countries examined

| | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **Laws, Codes, Decrees** | Building code BR 95<br>and for small buildings BR-S 85 (e. g. single family houses, BR-S 98 will be in force from 1.12.98 on) | Building Energy Codes<br><br>Building Thermal codes | Decree on Space Heating Demand<br>Decree on Heating Systems<br>Decree on Heating Costs<br><br>based on<br><br>Law on Energy Conservation | Building decree<br><br>Energy Performance Standard | Building regulations for energy efficiency<br>BBR 94<br>Design regulations BKR 94<br>based on Building Code of Statues |
| **Period** | Danish building codes have been revised in 1972, 1977,1982, 1985, 1995, 1998 | 1974 first decree on insulation standards. Two further steps in 1982 and 1989. The next step is planned for 1999 -2000 | 1977 first decree on space heating demand. Two further decrees in 1982 and 1995. Next decree expected in 2000 | Standards are in work since 1964. Since 1995 they are supplemented by standards for the overall energy performance | Standards are in work since 1975. Existing building regulations are from 1999, including the energy efficiency part from 1994 |
| **Applicability** | Construction of new houses differentiated between small and large buildings | Construction of new houses | Construction of new houses<br>new extensions of old buildings | Construction of new houses | Construction of new houses<br>new extensions of old buildings |

However this development is neither accompanied by a further regulation on retrofitting of the old building stock, nor by an extended control of the fulfilment of regulation requirements. So far the building codes are applicable in all European countries mainly to the construction of new buildings as shown in Table 2-4. Major renovations of old buildings are covered, but still no forcing of the retrofitting of old buildings is undertaken, in contrary to the case of boilers e. g. in the German decree on small boilers[5]. /Eichhammer, Schlomann 1997/ mention as possible reasons for this, first that additional costs cannot always be totally covered through energy savings, and second that social factors might play an addtional role.

For further analysis of standards a short methodological remark is necessary. /Eichhammer, Schlomann 1997/ have classified standards into four groups „which were distinguished by the different degree of integration of the building as a system. The more inte-

[5] In The Netherlands the mandatory retrofitting of buildings built before 1985 has been discussed, but is unlikely to be realised. Additionally, the missing of standards for thermal insulation of old buildings can not be used directly as an indicator for low retrofitting insulation levels in the other countries, because other policy measures may be used for retrofitting. For the countries examined they are found frequently in the bundle of subsidies, where they have a more voluntary character and where they are connected with investment incentives to overcome the financial obstacles mentioned above.

grative an approach is, the greater the flexibility permitted in details and the simpler the coefficients provided for a building which could be directly converted into a certificate which clearly and understandably shows the energetic value of a building“ /Eichhammer, Schlomann 1997, p. 2/. The four groups are:

- The *unit approach* which considers only the heat transmission through individual units/components of the building shell.
- The *average transmission through the building shell* gives a single value for the building shell and therefore allows the compensation of heat losses of different building components.
- The *maximum values of the heating demand of a building* includes alongside the heat transmission through building components, ventilation losses, heat increases due to solar heat recovery and internal heat sources in the house.
- The *fully integrated approach* also includes the heating supply system of the building in the calculation. This approach results in the integration of the thermal insulation and the heating system regulation.

Traditionally the thermal insulation ordinances started from a unit approach to regulate heat losses. Using the MURE[6] database it was concluded that considerable differences exist among the European countries concerning the integration level of regulation. The French situation was indicated as fully integrative, whereas e.g., the Swedish regulation standard was mentioned as less integrated, i. e. calculated on the building shell level (/Eichhammer, Schlomann 1997/). From the working papers produced within this project a slightly different picture has to be given.

**Table 2-5:** Classification of building standards

| Classification | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **Unit approach building shell** | Yes | No | No | Yes | No |
| **Average transmission building shell** | Yes | Yes | No | No | No |
| **Heating demand of buildings** | Yes | Yes | Yes | No | Yes |
| **Fully integrative approach** | No | Yes | No | Yes | No |

All of the countries mentioned in this paper have reached a quite similar level of calculation of the building system, i. e., at minimum the calculation of the heating demand of the entire building structure is in use (cf. the fat line running through Table 2-5 which indicates

6 Under the European Commission`s SAVE Programme the MURE (Mésures d’Utilisation Rationelle de l’Energie) database is developed.

the far most level reached). More than one “yes” in the column for one country means that various standards exist for the heating energy demand for a building.

At the stage of calculation every country has its own denomination of the calculated coefficients. The German regulation is taken as an example for examination, the central coefficient is calculated as follows:

1. Basically the heat losses of the building components are summed up.
2. Thereafter internal energy gains and solar yields are added.
3. Based on the results values for annual consumption are calculated.
4. Then the annual heating energy consumption is related to the heated building volume or to the heated dwelling surface.
5. Finally the counted values are compared to the maximum annual heating energy consumption permitted per individual dwelling. If the counted values exceed the maximum one has to refit e. g. building components or e. g., the relation between walls and windows.

The first three steps are forming the calculation whereas steps four and five are the assessment i. e., the comparison with insulation requirements. A European standard EN 832 for the calculation of the thermal performance of buildings exists for the first three steps[7], but it does not focus on the assessment of the calculated values. Therefore EN 832 does not allow comparison of the point of which the main differences are to expected.

Thus by comparing the calculation procedures of the countries examined the thesis can be proved that the main differences which hinder a direct comparability of regulations are located at the assessment step. Countries choose different values as basis for regulation and they relate these national coefficients to different aspects of the building system.

Therefore the main difference in the calculating methods of the examined countries lies on the stage on which the counted heat-loss is related to the aspect of the entire building (total building volume vs. surface building shell vs. heated floor).

Regarding these findings the comparison of maximum values must be viewed. Absolute standard values cannot be compared directly, which is not only true because of differences in climatic conditions. Therefore the energy performance of reference buildings under the different regulations is compared in section 0.

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[7] Broadly compared with the German calculation beside considerable similarities there exist following differences:

- EN 832 is a fully integrative approach using the classification mentioned above. The final heating energy demand for buildings is calculated in addition to the annual heating demand for building in the German regulation;
- The approach in EN 832 starts with the definition of heated zones, which is not made explicit in the German method;
- The heating demand for hot water is added in EN 832.

## 2.4 Taxes

This section deals with the treatment of residential space heating in the national tax systems. Applied types of taxes are presented and analyzed with respect to their objectives (budget financing or allocative respectively guiding effect). Also tax rates for selected fuels are compared.

Basically it is possible to tax fuel consumption or emission production. Taxes on the income side are not described because aspects of distribution are disregarded Four kinds of taxes are differentiated within the tax systems (cp. Table 2-6).

There are a few general similarities between the countries concerning these taxes:

- Normally taxes are implemented on a national level. So all households are affected and taxes are collected for the federal budget. This can be different for taxes having special fiscal objectives.
- In all countries under study value added taxes are also applied to the consumption of fuels. However, the percentage rates vary slightly over the different countries[8].

**Table 2-6:** Taxes on fuels or emissions in the countries examined in 1995

| | DK | F | D | NL* | S |
|---|---|---|---|---|---|
| **Type/Short description** | VAT<br>Taxes on fuels<br>Taxes on emissions | VAT<br>Taxes on fuels<br>Local taxes on electricity consumption | VAT<br>Taxes on fuels | VAT<br>Taxes on fuels<br>Regulatory energy tax<br>Special levy on final use | VAT<br>Taxes on fuels<br>Taxes on emissions<br>Special levy |
| **Energy carriers affected by taxes except VAT** | Oil<br>Electricity<br>Gas (from 1996 on[9])<br>Coal | Oil and LPG<br>Natural gas<br>Coal<br>Electricity | Oil<br>Gas | Oil<br>Gas<br>Electricity<br>Coal | Oil<br>Gas<br>Electricity<br>Other fuels |
| **Main Objective** | Allocative effects (Environmental)<br>Budget financing effects | Budget financing effects<br>Local investment on electricity networks | Budget financing effects | Allocative effects (regulatory energy tax)<br>Budget financing effects (others) | Allocative effects (Environmental) |

* NL: situation in 1996

8 Note that the situation of 1995 is reported. In the future further harmonization of VAT within the European Community can be expected.

9 Before 1996 the system in Denmark was complicated - with a shadow tax on natural gas. The gas utilities were allowed to sell the gas to the same price as oil including tax. The revenue was used to finance the natural gas grid.

An overview on the tax rates is given in Table 2-7. Particularly interesting is a short view on the induced price increases in the three countries examined which yet have levied taxes for further environmental objectives.

In The Netherlands a new tax on the final use of energy was introduced in 1996. For natural gas used by households, the rate increased from NLG 0.032 per $m^3$ (EUR 1.60 per MWh) in 1996 to NLG 0.160 per $m^3$ (EUR 7.98 per MWh) in 1999 (an amount of 800 $m^3$ remains untaxed).Through this tax (which also applies to electricity and oil) the Netherlands are expected to reach a $CO_2$ reduction of between 1.3 and 2.7 Mt until the year 2002[10]. However, despite the burden of taxes, natural gas prices for households in the Netherlands are still among the lowest in the EU.

**Table 2-7:** Taxes applied to energy carriers in the countries examined 1999

| Tax rates EUR/MWh | DK | F | D | NL | S*** |
|---|---|---|---|---|---|
| VAT Fuels | 25 % | 20.6 % | 16 % | 17.5 % | 25 % |
| Coal | 21.87 + VAT | VAT | VAT | 1.33 + VAT | 21.2 + VAT |
| Light Oil | 26.22 + VAT | 7.81 + VAT | 6.1 + VAT | 9.85 + VAT | 21.1 + VAT |
| Natural gas | 22.81 + VAT | 1.13 + VAT | 3.5 + VAT | 9.69 + VAT | 11.1 + VAT |
| Electricity | 85.22 (76.48*) + VAT | 9.9** + VAT | 10.2 + VAT | 23.82 + VAT | 17.6 + VAT |
| VAT = Value added tax, *Electricity for heat; ** Different local taxes on electricity (the national rate is around 8,5 % of the price of electricity); ** *Figures for Sweden refer to 1998. | | | | | |

In Denmark the already mentioned tax rate on natural gas will be around 6.8 EUR per GJ or 0.019 EUR per $m^3$ in the year 2000. In Sweden the total tax is 11.1 EUR/MWh (0,011 EUR/kWh) in 1998 including 23.5 % for the general energy tax and 76.5 % for the $CO_2$ tax. However, few numbers are available which could assess the quantitative effect of these taxes and the other fuel taxes on the specific energy use for residential space heating.

For Germany, where in 1995 no further energy taxes were applied beside those implemented by the mineral oil law, /Ebel et al. 1996/ calculate that a new energy tax at a level of 25 - 30 EUR/MWh for residential space heating consumption would open up an energy saving potential of 50 %. The new German government has introduced ecological taxes for heating oil (2 cent/l), gas (0.16 cent/kWh) and electricity for heating purposes (0.5 cent/kWh). The current level (1999) of the German tax on e. g., natural gas is 3.5 EUR/MWh if the gas is used for heating purposes.

Considering these price and volume effects of the taxes concerning energy for space heating taxes are found to be an important policy measure in all countries. Regarding struc-

10 Total emissions from combustion of fossil fuels stationary sources in 1995 were around 130 megatons.

tural effects, e. g., the reduction goals of about 2 Mt $CO_2$ emission in the Netherlands or the total amount of Swedish emission taxes, it could be shown that taxes are considerably important for structure guiding goals of energy policies. On the budget financing side the high rates of value added taxes play a considerable role, too.

## 2.5 Subsidies

This section compares subsidy schemes supporting a more efficient use of energy for residential space heating in the countries in question. For this comparison information on number, type and objectives of the subsidy schemes and the actors concerned as well as budgets spent have been collected.

First of all it can be stated that the share of government expenditures for subsidies aiming at energy conservation and the use of renewable energy has been 23.5 % of the total direct subsidies for energy purposes in the EU and its member states between 1990 and 1995. During this time around 2450 million EUR have been spent for conservation purposes out of the public budgets /Ruijgrok, Oosterhuis 1997/.

In the following special initiatives and programs concerning the residential energy sector are outlined. However, the total number of subsidies seems to decline. Many of the appointed programs which started in the past are phased out or will be stopped in the close future. In general most of national governments meanwhile concentrate on a few programs, e. g., in the case of Denmark, with actually five subsidy schemes aiming directly at the housing sector, Sweden with three, France and the Netherlands with one or two main programs (cf. Table 2-8).

**Table 2-8:** Type of subsidies in work in the countries examined

| | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **Short description** | Five subsidy schemes are aiming directly at the housing sector | One program for energy conservation | A couple of programs | Included in general retrofitting program | A few special schemes |
| **Type**<br>• **investment subsidies**<br>• **fiscal tax reductions**<br>• **interest reduced loans** | Investment subsidies | Fiscal tax credits for households | Mainly based on interest reduced loans | Investment subsidy | Partly investment subsidy<br>System of low-interest loans |
| **Actors** | Public | Public | Public | Public and private, i. e.<br>Energy suppliers | Public |
| **Subjects** | - Exploitation of renewable energy sources<br>- Conversion of heating system in old houses into district heating<br>- Subsidy for energy savings in dwellings owned by old-age pensioners<br>- Installation of central heating in houses with electricity based heating systems | - Energy retrofitting works | - Use of renewable energy carriers<br>- Investment in energy conservation technologies<br>- KfW program to support modernisation measures in dwellings in the new Länder<br>- KfW Program to reduce $CO_2$ emissions of the building stock<br>- Subsidies for low-energy houses | - Insulation subsidies for existing buildings<br>- Insulation subsidies for rented houses within the framework of general renovations<br>- Subsidies for energy efficient central heating boilers<br>- Other subsidies, e. g., for district heating and CHP | - Subsidies for bio-fueled power plants<br>- Subsidies for solar collectors (ended 1997)<br>- Subsidies for local wood fired stoves and storage tanks together with a maximum electrical power reducer<br>- Subsidies for connecting to the district heating grid (only for cases with direct electricity heating, started 1998) |

The German situation differs as the programs are in the responsibility of different institutions such as federal, regional and local organisations, which have launched their own schemes.

Different types of subsidies can be found when comparing the countries: direct investment subsidies, fiscal tax reductions for households as well as interest reduced loans (cp. Table 2-8). Direct investment subsidies are used the most in all countries examined. Denmark and the Netherlands used them for all their schemes, in Sweden they are used for the promotion of new technologies under the program of the rational use of energy (started 1988) and the reduction of the use of electricity for heating.

Three different objectives of subsidies can be found when comparing the countries (cf. Table 2-8):

- to improve the energy efficiency in residential space heating (often retrofitting of old buildings to overcome obstacles concerning investment decisions);
- to promote investment in renewable energy carriers;
- to shift the demand from one energy carrier to another (e.g., from electricity to district heating).

One interesting example for overcoming obstacles concerning investment decisions can be found in Denmark. In this country there is a scheme which especially promotes energy savings in dwellings which are owned by old-age pensioners. The background for the scheme was an investigation showing that old-age pensioners had higher expenses for heating than typical for households. The building must be built before February 1979. The subsidy covers up to 50 % of the investment /Leth-Petersen, Togeby 1998 a/.

Concerning actors and budgets an ongoing structural change has to be noted. Beside the mentioned activities of the public sector energy suppliers launch commercial subsidies. This is especially the case in France where investment grants are given to households choosing electric heating with high requirements for insulation in new construction. In the Netherlands by the end of 1993, the government has terminated its financial support for thermal insulation and energy efficient heating equipment. As from 1994, these subsidies were provided entirely by the distribution companies, within the framework of their Environmental Action Plan /Oosterhuis, Nieuwlaar 1998a/. Therefore these subsidies are no longer budget relevant and public spending has been reduced to zero (apart from investment grants within the framework of general renovations). For the federal budget of Germany this is quite similar because of the concentration on interest reduced loans and the repeal of the write off possibilities mentioned.

## 2.6 Other instruments

This section deals with different additional instruments in the countries examined. As there is such a broad range of other policy instruments to influence residential space heating consumption, only some examples are presented. Basically the following types of instruments may be distinguished:

- information policies which try to overcome information problems of different actors like households or investors;
- information and training of architects and craftsmen for optimizing planning and minimizing building failures;

- informational (audit and consultancy) schemes, which should work as further incentives for energy efficiency improvements by households as well as investors.

In Table 2-9 as an example the main information policies in the countries under study are listed. Major points to retain concerning information policies are:

- The total number of information campaigns seems to decline.
- Many of the appointed programs which started in the past are phased out.

**Table 2-9:** Information policies in the countries examined

| | DK | F | D | NL | S |
|---|---|---|---|---|---|
| **Type/Short description** | Little efforts on information campaigns.<br>Ongoing initiative is a leaflet supplied by the Ministry of Environment and Energy and supplemented by a public information telephone line<br>An Internet service with advice for all energy users has been started in 1998 by the Ministry | Between 1974 and 1992 information campaigns have been launched constantly.<br>Since 1993 no information campaigns were started except by energy suppliers | Various information programs and campaigns for households, architects, engineers, technicians and craftsmen.<br>Books and brochures have been published recently | Various information and counselling campaigns, projects and actions have been initiated by the government. These activities are now carried out mainly by the distribution companies | Energy consultants within the municipalities.<br>Information departments within the Swedish Council of Building Research and NUTEK |
| **Main objectives** | Households can use it to acquire information on how to save energy | Stimulate energy conservation and behaviour improvement<br>Give objective information for decision | Stimulate rational use of energy | Stimulate energy conservation | Provision of information on energy conservation to different target groups |

Measures for the information and training of architects and craftsmen like in Austria are seldom found in the countries examined (cf. /Voss-Uhlenbrock et al. 1998 b/). In Sweden demonstration projects embedded in the program for rational use of energy can be mentioned. The German parliament tried to improve the incentives for architects and engineers to reduce $CO_2$ emissions through an amendment to the code on fees for architects and engineers (HOAI). The payments for the architects' work should be better in the case of planning an increased use of renewable energy carriers.

Consultant and audits schemes vary broadly across Europe. Among the countries under study the most stringent strategy concerning the use of audits is found in Denmark where not only several consultant schemes are active but from 1997 on all buildings with an area less than 1,500 $m^2$ must have an energy label when they are sold[11]. Despite of being mandatory no control is made on the existing label. Therefore the rate of houses really checked is only around 50 %. For buildings that are larger than 1,500 $m^2$ an energy audit must be carried out by an approved consultant. A standardised format exists for the energy plan worked out within this audit. This includes an overview of the building, its installations and relevant projects for saving energy and water.

[11] Similar rules can be found in the United Kingdom (cp. /Eichhammer, Schlomann 1997/)

# 3 Modelling the energy consumption for space heating and the impact of policy instruments

How do policy instruments such as standards, taxes and subsidies influence the energy demand for residential space heating? This is the main research question addressed by the EPISODE project. It links elements of the policy sphere, i. e. policy instruments, to elements of the engineering / natural science sphere, i. e. energy demand and energy efficiency.

The most straightforward but theoretically least satisfying way to establish the linkage between policy instruments and residential space heating demand is to assume a black box with policy instruments as inputs and observed energy consumption as output. Thus the first aim of this section is to develop in detail a causal model which prevents from just data mining. However, data availability restrictions make further modifications of the model for the empirical application unavoidable.

Therefore the second aim of this section is to present a scheme of analysis on the basis of a careful compromise between actual data availability and the demand of the theoretical causal model.

Going from theoretical considerations to empirically applicable models the remainder of this chapter is structured as follows:

- At given building characteristics and at given climate, the energy consumption for space heating can be described on the one hand by technical relationships and on the other hand by the utilisation patterns of the occupants of the building. This is described in the following section 3.1.
- These relationships may be exploited for technical simulations by means of a building model. This model and its necessary input data are sketched in section 3.2.
- Another possibility is to derive a regression model from the technical relations, following the lines of the seminal work by /Dubin 1985/. How this can be done is depicted in section 3.3, with a focus on the building shell, as opposed to the consideration of the heating system by /Dubin 1985/.
- An important point to account for is that the building characteristics are influenced by investment decisions, e. g. investment in capital goods such as a new boiler or an improved insulation. Therefore investment variables (which may be monetary or physical ones) enter the technical model of section 3.3 and have in turn to be explained by some kind of investment model. This is discussed in section 3.4. Policy instruments then influence the investment decision in energy saving capital goods (cf. section 3.4) and they may also influence the actual production of space heat.
- Finally the econometric issues that have to been tackled and the approach to be taken are documented in section 3.5.

### 3.1 Energy consumption for space heating according to technical guidelines

Different norms or guidelines may be used as a starting point for an analysis of the annual space heating demand of residential buildings. One possibility is to start from the European Norm DIN EN 832 /DIN 1992/. Further possible starting points are national norms and guidelines, e. g. the German guideline VDI 2067-2 /VDI 1991/ in combination with the German norm DIN 4701 /DIN 1983/ referenced in this guideline. In principle both possibilities differ not very much and would lead to similar models. Here the latter is chosen as it offers a calculation method for the final energy demand (instead of the useful energy demand in DIN EN 832). The draft version of guideline VDI 2067 from June 1998 (cp. /VDI 1998a/, /VDI 1998b/) is not used here, although it offers a far more exact calculation method compared to the version of 1991. As this draft version of VDI 2067 is based on numerical calculation of 8760 hourly values it is no useful basis for an econometric model to be derived in this context. To facilitate the understanding in the following some equations have already been simplified compared to the version proposed in the guideline.

According to guideline VDI 2067-2 (1991) the overall annual heat demand for space heating of a building is defined as:

$$Q_{\mathrm{Ha}} = E_{\mathrm{Ha}} \cdot \eta_{\mathrm{ges}} \qquad (3\text{-}1)$$

with:

$Q_{\mathrm{Ha}}$ - Annual heat demand
$E_{\mathrm{Ha}}$ - Annual energy consumption for space heating
$\eta_{\mathrm{ges}}$ - Overall efficiency of heating system

$E_{\mathrm{Ha}}$, the annual energy consumption for space heating, can be observed in the available data bases and is the basic variable to be explained in our analysis.

The overall efficiency of the heating system is the product of the boiler efficiency and the distribution efficiency (the latter being below 1 for central heating systems):

$$\eta_{\mathrm{ges}} = \eta_{\mathrm{a}} \cdot \eta_{\mathrm{V}} \qquad (3\text{-}2)$$

with:

$\eta_{\mathrm{a}}$ - Overall annual efficiency of the boiler(s)
$\eta_{\mathrm{V}}$ - Overall annual efficiency of distribution system

A simplified specification of $Q_{\mathrm{Ha}}$ is given with the following equation:

$$Q_{\mathrm{Ha}} = f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot f_5 \cdot f_6 \cdot 24 \cdot z \cdot \dot{Q}_{\mathrm{Geb}} - f_7 (Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}}) \qquad (3\text{-}3)$$

with:

$f_1$ - Correction term for additional ventilation
$f_2$ - Correction term for reduced heating time
$f_3$ - Correction term for partially not heated areas
$f_4$ - Correction term for controlling equipment of the heating system

$f_5$ - Correction term for temperature differences of room temperature compared to average room temperature

$f_6$ - Correction term for temperature differences of outside temperature compared to average outside temperature

$z$ - Number of heating days

$\dot{Q}_{\mathrm{Geb}}$ - Heat demand of a building (power) in W according to DIN 4701-2 (1983)

$f_7$ - Correction term concerning the use of internal heat sources and solar gains

$Q_{\mathrm{Sa}}$ - Solar gains

$Q_{\mathrm{Ia}}$ - Gains from internal heat sources

All these correction terms reflect more or less complicated functions of different technical or behavioural aspects, e. g.

$f_1$ = f(air exchange rate, room height, difference between inside and outside temperature, ...)

$f_2$ = f(heating time, heat storage capacity of building components, ...)

$Q_{\mathrm{Sa}}$ = f(window area, window orientation, other window features, storage mass of building components, climatic conditions, ...)

$f_7$ = $f_{\mathrm{F}}\ \eta_{\mathrm{F}}$

$f_{\mathrm{F}}$ = f(controlling equipment)

$\eta_{\mathrm{F}}$ = $0.86 \exp(-0.91 Q_{\mathrm{Sa}}/Q_{\mathrm{Ia}})$

The heat demand of a building (power) is defined according to DIN 4701-2 (1983):

$$\dot{Q}_{\mathrm{Geb}} = \dot{Q}_{\mathrm{T}} + \dot{Q}_{\mathrm{L}} \tag{3-4}$$

with:

$\dot{Q}_{\mathrm{T}}$ - Transmission losses

$\dot{Q}_{\mathrm{L}}$ - Airing and ventilation losses

The transmission losses may be calculated as follows:

$$\dot{Q}_{\mathrm{T}} = \sum_{\mathrm{j}} A_{\mathrm{j}} \cdot u_{\mathrm{N,j}} \cdot (\vartheta_{\mathrm{i,j}} - \vartheta_{\mathrm{a}}) \tag{3-5}$$

with:

j - Index of building components exposed to the outside

$A$ - Surface of the building component

$u_{\mathrm{N}}$ - U-value of the building component

$\vartheta_{\mathrm{i}}$ - Room temperature

$\vartheta_{\mathrm{a}}$ - Outside temperature

The airing and ventilation losses mainly depend on three different factors. In old buildings they are usually dominated by airing losses through leakages resulting from a bad building substance, in the case of newer buildings without air conditioning respectively mechanical ventilation they are mainly influenced by the occupants' behaviour concerning window opening and in the case of air conditioning or mechanical ventilation the main impacts are those of the technical features of the ventilation system. In general the airing and ventilation losses may be expressed as a function of the volume that has to be ventilated and of the temperature difference between the air leaving the building and the outside temperature and it should not be less than:

$$\dot{Q}_{\mathrm{L\,min}} = \beta_{\min} \cdot V_{\mathrm{R}} \cdot c \cdot \rho \cdot (\vartheta_{\mathrm{Li}} - \vartheta_{\mathrm{a}}) \tag{3-6}$$

with:

| | | |
|---|---|---|
| $\dot{Q}_{\mathrm{L\,min}}$ | - | Minimum annual heat demand for airing and ventilation |
| $\beta_{\min}$ | - | Minimum air exchange rate |
| $V_{\mathrm{R}}$ | - | Volume of rooms |
| $c$ | - | Heat capacity of air |
| $\rho$ | - | Density of air with temperature of leaving air |
| $\vartheta_{\mathrm{Li}}$ | - | Temperature of leaving air |
| $\vartheta_{\mathrm{a}}$ | - | Outside temperature |

Using equation ( 3-1 ) to ( 3-6 ) the annual energy consumption for space heating is:

$$\begin{aligned} E_{\mathrm{Ha}} &= \eta_{ges}^{-1} \cdot (f_1 \cdot f_2 \cdot f_3 \cdot f_4 f_5 \cdot f_6 \cdot 24 \cdot z \cdot \dot{Q}_{\mathrm{Geb}} - f_7(Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}})) \\ &= \eta_a^{-1} \cdot \eta_V^{-1} \cdot (f_1 \cdot f_2 \cdot f_3 \cdot f_4 f_5 \cdot f_6 \cdot 24 \cdot z \cdot (\dot{Q}_{\mathrm{T}} + \dot{Q}_{\mathrm{L}}) - f_7(Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}})) \\ &= \eta_a^{-1} \cdot \eta_V^{-1} \cdot \Big(f_1 \cdot f_2 \cdot f_3 \cdot f_4 f_5 \cdot f_6 \cdot 24 \cdot z \cdot \Big(\sum_{\mathrm{j}} A_{\mathrm{j}} \cdot u_{\mathrm{N,j}} \cdot (\vartheta_{\mathrm{i,j}} - \vartheta_{\mathrm{a,j}}) + \\ &\quad \beta_{\min} \cdot V_R \cdot \rho \cdot c \cdot (\vartheta_{\mathrm{Li,j}} - \vartheta_{\mathrm{a,j}})\Big) - f_7(Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}})\Big) \end{aligned} \tag{3-7}$$

Basically there are two possibilities how to use this equation:

- as a technical equation (engineering approach)
- as basis for a regression model (statistical or econometric approach).

The advantage of the first possibility is that no statistical estimations are necessary and that the main technical features of the building and their influence on the heating demand are taken into consideration. On the other hand only single buildings may be analysed by such an equation as there is need for a considerable amount of technical and behavioural data for each building. The second possibility offers the chance to connect a technical model with economic models and to analyse large amounts of data sets respectively buildings. The disadvantage of the statistical approach is that technical information on the building is less detailed and that therefore many of the physically motivated relations have to be simplified and proxies have to be used to describe these relations. Within the present research both approaches have been applied. In the following first the technical building simulation derived from the above formula is sketched in the following section, then the derivation of an regression model is discussed in the later sections.

## 3.2 Technical building model

The equations in the previous section may be implemented in a computer program (in occurrence an Excel-spreadsheet comparable to /Blesl 1999/) and, given that the necessary input data are available, used to determine the heating energy consumption of a building. In the context of the present research, such a building model is particularly interesting to compare the building standards in the different European countries.

Therefore two reference buildings have been defined, based on data from /Ebel et al. 1992/. One building type is a detached single family house (SFH) with 160 $m^2$ dwelling space, the other one is a small multi-familiy house (MFH) with 8 dwellings and 600 $m^2$. The geometric data, which are assumed to be similar across countries, are given in Table 3-1.

**Table 3-1:** General geometric input data

| Geometric data | | SFH | MFH |
|---|---|---|---|
| Roof exposed to outside air | m² | 101 | 248 |
| Wall exposed to outside air | m² | 155 | 399 |
| Floor separating from cellar | m² | 83.4 | 248 |
| Windows South | m² | 6.02 | 29 |
| Windows East | m² | 17.4 | 60 |
| Windows West | m² | | |
| Windows North | m² | 3.6 | 10 |
| Heated surface | m² | 161 | 595 |
| Net heated volume | m³ | 403 | 1636 |

The second important category of input data are the U-values and $R_s$-values describing the heat resp. radiation transmission of the different building components. These are varying across countries and building types, and have also evolved during time with the tightening of the building codes. Table 3-2 and Table 3-3 show the input data for the two building types which correspond to the latest building standards in vigour in the countries. Please note, that the data of last two rows of Table 3-2 and Table 3-3 contain general input data.

Besides these building data, data on the occupants and their behaviour are necessary. The correction factors $f_1$ to $f_6$ are for sake of simplicity set to 1, but to determine the internal gains and the airing and transmission losses the data shown in Table 3-4 are used.

**Table 3-2:** Country specific U-values and $R_c$-values for single-family houses

| **U-values, $R_c$-values** | | **NL** | **DK** | **S** | **F** | **D** |
|---|---|---|---|---|---|---|
| Roof exposed outside | W/(m²K) | 0.330 | 0.120 | 0.124 | 0.450 | 0.220 |
| Wall exposed outside | W/(m²K) | 0.330 | 0.240 | 0.192 | 0.650 | 0.447 |
| Floor exposed cellar | W/(m²K) | 0.330 | 0.200 | 0.223 | 0.450 | 0.380 |
| Windows South | W/(m²K) | 1.800 | 1.300 | 1.400 | 2.450 | 1.300 |
| Windows East | W/(m²K) | 1.800 | 1.300 | 1.400 | 2.450 | 1.300 |
| Windows West | W/(m²K) | 1.800 | 1.300 | 1.400 | 2.450 | 1.300 |
| Windows North | W/(m²K) | 1.800 | 1.300 | 1.400 | 2.450 | 1.300 |
| $R_c$-values windows South | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-values windows East | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-value windows West | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-values windows North | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| Share of glass in windows | - | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Shading and dirtying | - | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |

**Table 3-3:** Country specific U-values and $R_c$-values for multi-family houses

| **U-values, $R_c$-values** | | **NL** | **DK** | **S** | **F** | **D** |
|---|---|---|---|---|---|---|
| Roof exposed outside | W/(m²K) | 0.330 | 0.130 | 0.140 | 0.450 | 0.220 |
| Wall exposed outside | W/(m²K) | 0.330 | 0.250 | 0.230 | 0.650 | 0.405 |
| Floor exposed cellar | W/(m²K) | 0.330 | 0.220 | 0.270 | 0.450 | 0.380 |
| Windows South | W/(m²K) | 1.800 | 1.300 | 1.500 | 2.450 | 1.300 |
| Windows East | W/(m²K) | 1.800 | 1.300 | 1.500 | 2.450 | 1.300 |
| Windows West | W/(m²K) | 1.800 | 1.300 | 1.500 | 2.450 | 1.300 |
| Windows North | W/(m²K) | 1.800 | 1.300 | 1.500 | 2.450 | 1.300 |
| $R_c$-values windows South | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-values windows East | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-value windows West | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| $R_c$-values windows North | - | 0.600 | 0.600 | 0.600 | 0.600 | 0.600 |
| Share of glass in windows | - | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Shading and dirtying | - | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |

**Table 3-4:** General input data of the category "use"

| **Use** | | **SFH** | **MFH** |
|---|---|---|---|
| Number of persons | P | 4 | 17 |
| Daily occupancy duration | h/day | 12 | 12 |
| Average heating supply per person | W/P | 80 | 80 |
| Energetic relevant air exchange rate | 1/h | 0.6 | 0.6 |
| Specific heat storage capacity air | Wh/(m³ K) | 0.33 | 0.33 |
| Specific heat storage capacity water | Wh/(l K) | 1.16 | 1.16 |

Furthermore of course climatic data are needed to determine the heating energy consumption. Table 3-5 contains the country specific input data which are the same for single- and multi-family buildings. The unit of solar and sky radiation is "kWh/(m²a)" but it is important to note, that the values shown in Table 3-5 only include the solar and sky radiation during the heating period. For France, where climatic differences within the country are important, the climatic zone H2 (median value) is taken as basis for the calculations. Also for Sweden one of the four zones (Stockholm, zone 3) defined in the building code is chosen.

**Table 3-5:** Country specific climatic input data

| **Climatic data** | | **NL** | **DK** | **S** | **F** | **D** |
|---|---|---|---|---|---|---|
| Duration of heating period | d/a | 242 | 274 | 274 | 217 | 227 |
| Degree days* | Kd/a | 3550 | 3191 | 4355 | 2850 | 3845 |
| Solar and sky radiation Horizontal** | kWh/(m²a) | 421 | 536 | 518 | 384 | 360 |
| Solar and sky radiation South** | kWh/(m²a) | 430 | 604 | 519 | 442 | 370 |
| Solar and sky radiation East** | kWh/(m²a) | 271 | 361 | 342 | 248 | 220 |
| Solar and sky radiation West** | kWh/(m²a) | 271 | 361 | 342 | 248 | 230 |
| Solar and Sky radiation North** | kWh/(m²a) | 172 | 173 | 175 | 127 | 140 |
| * /Eichhammer, Schlomann 1997/; ** during the heating period | | | | | | |

Finally to calculate the final energy consumption for space heating the average annual efficiency of the heating system is needed. Table 3-6 shows the country specific values which are the same for single- and multi-family buildings.

**Table 3-6:** Country specific data for the average annual efficiency of the heating system

| **Heating system** | | **NL** | **DK** | **S** | **F** | **D** |
|---|---|---|---|---|---|---|
| Average annual efficiency heating system | - | 0.855 | 0.850 | 0.850 | 0.760 | 0.850 |

## 3.3 Econometric model of heating energy consumption

As shown in the previous section, the use of the technical relationships to determine the heating energy consumption requires considerable knowledge on the building under consideration. Furthermore behavioural aspects can only be treated in the technical model by means of assumptions. But then also the impact of policy measures like taxes or subsidies, which are only effective by modifying utilisation or investment behaviour, may not be adequately treated within the technical model. Hence in the following an econometric model of heating energy consumption is derived, taking the technical equations as starting point and introducing simplifications and proxies (section 3.3.1) in order to cope with existing statistical (micro) data. In section 3.3.2 then the econometric model specification is discussed and in section 3.3.3 its possible application. Thereby only the energy use in a given building is considered, the modelling of investment possibilities is considered in section 3.4

### 3.3.1 Moving towards an econometric model

Starting from the technical equation ( 3-7 ) one may assume a building of rectangular ground floor and simple shape as shown in **Figure 3-1** to relate the heating energy consumption to statistically observable values like the dwelling space. The heat demand of the building $\dot{Q}_{\mathrm{Geb}}$ may be written - under the additional assumption of homogenous temperature in the building - as:

$$\begin{aligned}
&\dot{Q}_{\mathrm{Geb}} = \dot{Q}_{\mathrm{T}} + \dot{Q}_{\mathrm{L}} = \\
&(a \cdot b \cdot u_{\mathrm{Fl}} + \left(2 \cdot a \cdot h \cdot s + 2 \cdot b \cdot h \cdot s + a^2 \cdot \tan\varphi - A_{\mathrm{Win}}\right) \cdot u_{\mathrm{Wa}} + \\
&A_{\mathrm{Win}} \cdot u_{\mathrm{Win}} + \frac{a \cdot b}{\cos\varphi} \cdot u_{\mathrm{Ro}}) \cdot (\vartheta_{\mathrm{i}} - \vartheta_{\mathrm{a}}) + \\
&\beta_{\min} \cdot \rho \cdot c \cdot (a \cdot b \cdot h \cdot s + a^2 \cdot b \cdot \tan\varphi) \cdot (\vartheta_{\mathrm{Li}} - \vartheta_{\mathrm{a}})
\end{aligned} \qquad (3\text{-}8)$$

with:

| | | |
|---|---|---|
| $a$ | - | Width |
| $b$ | - | Length |
| $h$ | - | Room height |
| $\varphi$ | - | Angle of inclination |
| $s$ | - | Number of floors |
| $A_{\mathrm{Win}}$ | - | Window area |
| $u_{\mathrm{Fl}}$ | - | U-value of floor |
| $u_{\mathrm{Wa}}$ | - | U-value of walls |
| $u_{\mathrm{Win}}$ | - | U-value of windows |
| $u_{\mathrm{Ro}}$ | - | U-value of roof |

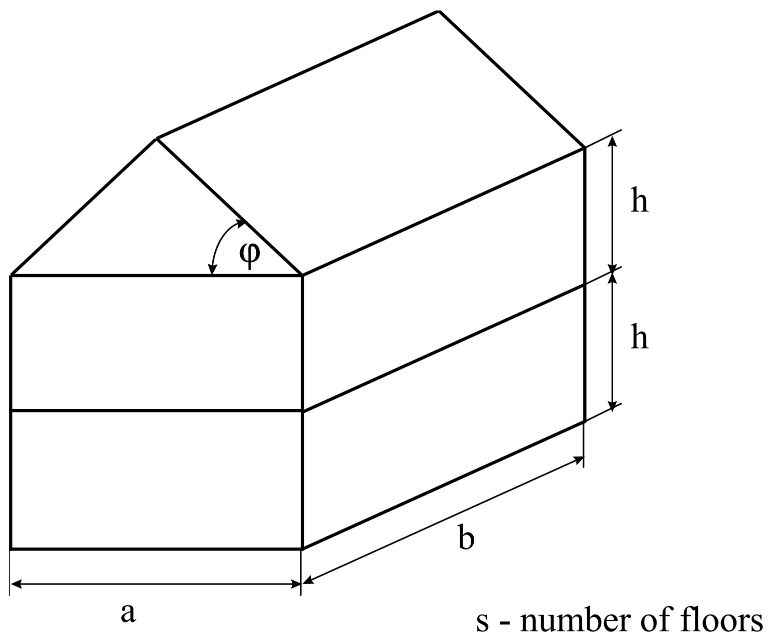


**Figure 3-1:** Simplified reference building

For this geometry the dwelling space $D$ is equal to the ground floor multiplied by the number of floors and $a$ is assumed proportional to $b$ with $\lambda$ being the factor of proportionality, so one obtains:

$$D = a \cdot b \cdot s = \lambda \cdot a^2 \cdot s \qquad (3\text{-}9)$$

Using equation ( 3-9 ) and replacing the different u-values by an average u-value of the building $u_{\mathrm{m}}$, equation ( 3-8 ) can be written as follows:

$$\begin{aligned}\dot{Q}_{\mathrm{Geb}} &= \dot{Q}_{\mathrm{T}} + \dot{Q}_{\mathrm{L}} \\ &= \left( \frac{D}{s} + 2 \cdot \sqrt{\frac{D}{\lambda \cdot s}} \cdot h \cdot s + 2 \cdot \sqrt{\frac{\lambda \cdot D}{s}} \cdot h \cdot s + \frac{D}{\lambda \cdot s} \cdot \tan\varphi + \frac{D}{s \cdot \cos\varphi} \right) \cdot \\ &\quad u_{\mathrm{m}} \cdot (\vartheta_{\mathrm{i}} - \vartheta_{\mathrm{a}}) + \beta_{\min} \cdot c \cdot \rho \cdot (D \cdot h + \sqrt{\frac{D^3}{\lambda \cdot s^3}} \cdot \tan\varphi) \cdot (\vartheta_{\mathrm{Li}} - \vartheta_{\mathrm{a}})\end{aligned} \qquad (3\text{-}10)$$

Introducing equation ( 3-10 ) into equation ( 3-7 ) and replacing the correction terms $f_1$ to $f_6$ and the heating days $z$ by an average correction term $f_{\mathrm{m}}$ leads to the following equation:

$$\begin{aligned}E_{\mathrm{Ha}} &= \eta_{ges}{}^{-1} \cdot f_m \cdot \\ &[\left( \frac{D}{s} + 2 \cdot \sqrt{\frac{D}{\lambda \cdot s}} \cdot h \cdot s + 2 \cdot \sqrt{\frac{\lambda \cdot D}{s}} \cdot h \cdot s + \frac{D}{\lambda \cdot s} \cdot \tan\varphi + \frac{D}{s \cdot \cos\varphi} \right) \cdot u_{\mathrm{m}} \cdot (\vartheta_{\mathrm{i}} - \vartheta_{\mathrm{a}}) + \\ &\beta_{\min} \cdot c \cdot \rho \cdot (D \cdot h + \sqrt{\frac{D^3}{\lambda \cdot s^3}} \cdot \tan\varphi) \cdot (\vartheta_{\mathrm{Li}} - \vartheta_{\mathrm{a}}) - f_7 \cdot (Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}})]\end{aligned} \qquad (3\text{-}11)$$

As it is unrealistic to have data available containing all information necessary to determine equation ( 3-11 ), simplifications have to be made and possible proxies for different variables may be chosen. Some proxies are specified in Table 3-7.

**Table 3-7:** Different heat losses and heat sources and possible proxies to describe them

| **Heat losses/source** | **Variable** | **Influencing factors** | **Possible proxies** |
|---|---|---|---|
| Losses of boiler | $\eta_a$ | Type of boiler<br>Type of heating system<br>Temperatures<br>Control system | Vintage of boiler<br>Energy carrier used |
| Losses of heating system | $\eta_V$ | Central/decentral<br>Thickness and insulation of tubes and pumps<br>Thermostatic valves<br>Temperatures in the system<br>Control system | Vintage of building<br>Vintage of heating system<br>Type of heat generation |
| Transmission losses | $Q_T$ | Surface of building (length, width, room height, number of floors)<br>U-values of walls, roof, ceilings, floors, windows<br>Inside and outside temperature during the heating period<br>Other weather conditions | Area of walls resp. dwelling space and room height<br>Number of floors<br>Type of roof<br>Vintage of building<br>Retrofitted yes/no<br>Kind of retrofitting<br>Type of building<br>Share of windows<br>Environmental awareness<br>Energy price |
| Losses through ventilation | $Q_L$ | Tightness of building<br>Mass transfer (volume of building),<br>Temperatures of air leaving the building | Vintage of building<br>Air conditioning resp. mechanical ventilation<br>Heat recovery<br>Environmental awareness<br>Energy price |
| Human heat sources | $Q_{Ia}$ | Number of persons and their time presence and type of activities | Number of persons<br>Number of employed<br>Number of children |
| Heat sources of lighting and engines | $Q_{Ia}$ | Number of persons and their time presence and type of activities<br>Penetration rates of appliances | Number of persons<br>Number of employed<br>Number of children<br>Geographical latitude<br>Penetration rate of appliances |
| Solar heat gains | $Q_{Sa}$ | Location and weather conditions<br>Inside and outside temperature during the heating period<br>Window surface and orientation<br>Heat storage mass in the building<br>Control system | Location of building<br>Geographical latitude<br>Share of windows<br>Type of building<br>Vintage of building<br>Building type<br>Vintage of boiler |

For the occupants' behaviour socioeconomic characteristics like the age of the reference person, the household size or the income may be taken as proxies. In principle it would also be very interesting to include measures of e.g. 'environmental awareness' or other attitudes. However such data are not available in data bases on buildings and heating energy consumption, nor are proxies like the membership in an environmental organisations or the purchase of bio-food.

### 3.3.2 Basic econometric model specification

Based on the simplifications and proxies derived in the previous section, in this section a specification for the econometric model is derived, assuming the availability of the data described in Table 3-8. For the application in the different countries partly some variables have to be dropped or modified due to data restrictions (cf. section 4.1).

**Table 3-8:** Basic variables of econometric heating energy use model

| Observation | Variable | Type of variable |
|---|---|---|
| Heating energy consumption | $E_{\mathrm{Ha}}$ | Continuous |
| Type of heating system | $T_{\mathrm{Hs}}$ | Dummies |
| Energy carrier | $E$ | Dummies |
| Vintage class of boiler | $V_{\mathrm{Bo}}$ | Dummies |
| Vintage class of building | $V_{\mathrm{Bu}}$ | Dummies, categories corresponding to changes in standards |
| Type of building | $T_{\mathrm{Bu}}$ | Dummies |
| Dwelling space | $D$ | Continuous |
| Mechanical ventilation or air-conditioning yes/no | $M$ | Dummies |
| Retrofitted yes/no | $R$ | Dummies |
| Degree days | $G$ | Continuous |
| Household characteristics, e. g. | $z_c$ | |
| Number of adults | $z_1$ | Integer |
| Number of employed | $z_2$ | Integer |
| Number of children | $z_3$ | Integer |
| Income classes | $z_4$ | Dummy |
| Age classes of reference person | $z_5$ | Dummy |
| Energy price | $p$ | Continuous |
| Available subsidies | $S$ | Integer |
| Other policy instruments (e. g. audits) | $O$ | Dummies, one per instrument |

Based on equation ( 3-11 ) the next step is to choose functional forms to express those relations respectively variables that are not observed directly but have to be approximated by proxies. It is assumed that the overall efficiency of the heating system $\eta_{\mathrm{ges}}$ depends on the vintage class of the boiler $V_{\mathrm{Bo}}$ and the combination of energy carrier and boiler type $ET$. The following functional form is chosen:

$$(\eta_a + \eta_V)^{-1} = \eta_{ges}^{-1} = \alpha_0 + \sum_h \alpha_{1,h} \cdot V_{Bo,h} + \sum_i \alpha_{2,i} \cdot ET_i + \varepsilon_1 \quad (3\text{-}12)$$

with:

$\alpha_0$ - Constant

$\alpha_1$, $\alpha_2$ - Regression coefficients

$V_{Bo}$ - Vintage class of boiler

$ET$ - Combination of heating system and energy carrier

h - Index of boiler vintage classes

i - Index of combinations of boiler type and energy carrier

$\varepsilon_1$ - Error term

Assuming that the building shape, i. e. $\varphi$ and $s$, is depending on the type of the building $T_{BU}$ and using $T_{BU}$ as a proxy for the shape of the building the term in equation ( 3-11 ), which is approximating the influence of the surface of the building can be written as follows:

$$\left(\frac{D}{s} + 2 \cdot \sqrt{\frac{D}{\lambda \cdot s}} \cdot h \cdot s + 2 \cdot \sqrt{\frac{\lambda \cdot D}{s}} \cdot h \cdot s + \frac{D}{\lambda \cdot s} \cdot \tan\varphi + \frac{D}{s \cdot \cos\varphi}\right) = \beta_1 \cdot D + \beta_2 \cdot \sqrt{D} + \sum_j \beta_{3,j} \cdot D \cdot T_{Bu,j} + \varepsilon_2 \quad (3\text{-}13)$$

with:

$\beta_1$, $\beta_2$, $\beta_3$ - Regression coefficients

$T_{Bu}$ - Type of building

j - Index of building types

$\varepsilon_2$ - Error term

Furthermore the term in equation ( 3-11 ), which is approximating the influence of the building volume can be specified as follows:

$$\left(D \cdot h + 2 \cdot \sqrt{\frac{D^3}{\lambda \cdot s^3}} \cdot \tan\varphi\right) = \gamma_1 \cdot D + \sum_j \gamma_{2,j} \cdot D^{3/2} \cdot T_{Bu,j} + \varepsilon_3 \quad (3\text{-}14)$$

with:

$\gamma_1$, $\gamma_2$ - Regression coefficients

$\varepsilon_3$ - Error term

Assuming that the vintage class of the building $V_{Bu}$ and the retrofitting $R$ are explaining variables of the average u-value of the building $u_m$, this may be specified as follows:

$$u_m = \iota_0 + \sum_k \iota_{1,k} \cdot V_{Bu,k} + \sum_l \iota_{2,l} \cdot R_l + \varepsilon_4 \quad (3\text{-}15)$$

with:

$u_m$ - Average u-value of the building

$\iota_0$ - Constant

$\iota_1$, $\iota_2$ - Regression coefficients

$R$ - Retrofitting
k - Index of vintage classes
$l$ - Index of retrofit measures
$\varepsilon_4$ - Error term

Assuming that the number of degree days $G$ and the energy price $p$ are determining with further unobserved behavioural aspects the difference between inside and outside temperature, the temperature difference may be specified as follows:

$$\vartheta_{\mathrm{i}} - \vartheta_{\mathrm{a}} = \kappa_0 \cdot p^{\kappa_1} \cdot G^{\kappa_2} + \varepsilon_5 \tag{3-16}$$

with:

$\kappa_0$, $\kappa_1$, $\kappa_2$ - Regression coefficients
$p$ - Energy price
$G$ - Number of degree days
$\varepsilon_5$ - Error term

To determine ventilation losses additionally mechanical ventilation and heat recovery play a role. Assuming $M$ being a valuable proxy for this, the relevant temperature difference may be written as:

$$\vartheta_{\mathrm{iL}} - \vartheta_{\mathrm{a}} = \nu_0 \cdot p^{\nu_1} \cdot M \cdot G^{\nu_2} + \varepsilon_6 \tag{3-17}$$

with:

$\nu_0$, $\nu_1$, $\nu_2$ - Regression coefficients,
$M$ - Mechanical ventilation,
$\varepsilon_6$ - Error term.

Internal gains and solar gains may be assumed to be influenced by building features, i.e. the type of building $T_{\mathrm{Bu}}$ as a proxy for window size and orientation, degree days $G$ as a proxy for weather conditions and some household characteristics, i.e. number of adults $z_1$ and number of children $z_3$ as proxy for the number of sources, number of employed $z_2$ and children $z_3$ as proxies for the presence in the building. Solar gains furthermore may be influenced by the retrofit activities of the household, e.g. by large windows. Using these proxies, e.g. the following functional form can be chosen:

$$Q_{\mathrm{Sa}} + Q_{\mathrm{Ia}} = \omega_0 + \sum_{\mathrm{j}} \omega_{1,\mathrm{j}} T_{\mathrm{Bu,j}} + \omega_2 G + \sum_{\mathrm{m}} \omega_{3,\mathrm{m}} z_{\mathrm{m}} + \omega_4 R + \varepsilon_7 \tag{3-18}$$

with:

$\omega_0 \ldots \omega_4$ - Regression coefficients
m - Index household characteristics
$z_1$ - Household size
$z_2$ - All household members employed
$z_3$ - Income
$z_4$ - Age of reference person

$\varepsilon_7$ - Error term

Please note that the functional forms of equation ( 3-12 ) and equation ( 3-15 ) to ( 3-18 ) are arbitrarily chosen whereas the form of equation ( 3-13 ) is motivated by physical facts.

### 3.3.3 Application possibilities

Using the above specifications the heating energy consumption equation ( 3-11 ) may be written as:

$$\begin{aligned}
E_{Ha} = &\left(\alpha_0 + \sum_{\mathrm{h}} \alpha_{1,\mathrm{h}} \cdot V_{\mathrm{Bo,h}} + \sum_{\mathrm{i}} \alpha_{2,\mathrm{i}} \cdot ET_{\mathrm{i}} + \varepsilon_1\right) \cdot \\
&[(\beta_1 \cdot D + \beta_2 \cdot \sqrt{D} + \sum_{\mathrm{j}} \beta_{3,\mathrm{j}} \cdot D \cdot T_{\mathrm{Bu,j}} + \varepsilon_2) \cdot \\
&(\iota_0 + \sum_{\mathrm{k}} \iota_{1,\mathrm{k}} \cdot V_{\mathrm{Bu,k}} + \iota_2 \cdot R + \varepsilon_3) \cdot (\kappa_0 \cdot p^{\kappa_1} \cdot G^{\kappa_2} + \varepsilon_5) + \\
&(\gamma_1 \cdot D + \sum_{\mathrm{j}} \gamma_{2,\mathrm{j}} \cdot D^{3/2} \cdot T_{\mathrm{Bu,j}} + \varepsilon_5) \cdot (\nu_0 \cdot p^{\nu_1} \cdot M \cdot G^{\nu_2} + \varepsilon_6) \\
&- (\omega_0 + \sum_{\mathrm{j}} \omega_{1,\mathrm{j}} T_{\mathrm{Bu,j}} + \omega_2 G + \sum_{\mathrm{m}} \omega_{3,\mathrm{m}} z_{\mathrm{m}} + \omega_4 R + \varepsilon_7)]
\end{aligned} \qquad (3\text{-}19)$$

There are several possibilities how to treat such a non-linear equation, e. g.

- use as a non-linear regression model,
- linearisation with the help of a tailor approximation,
- taking logarithms and linearising then.

Additional options are to

- simplify the equation by heroic assumptions,
- replace different coefficients by technical coefficients, e. g. using average values of boiler efficiencies for different classes of boilers and types of heating systems,
- use the specific consumption per m$^2$ as explained variable.

The advantage of the estimation of the non-linear regression model is that the fewest approximations have to be made. An inconvenient is that such a model needs the most complicate estimation technique, although meanwhile non-linear ordinary least squares (NL-OLS) estimation techniques are almost standard. Additionally and probably more importantly serious problems of collinearity may occur with the multitude of influencing variables.

Linearisation with the help of a tailor approximation is a very straightforward econometric treatment which leads to a rather simple model. The disadvantage of this approach is that the physical facts are not taken into consideration and thus interpretation of the coefficients is difficult.

Advantages and disadvantages of the third possibility - to take logarithms and linearise the problem - are in principle similar to the ones of the linearisation with the help of a tailor approximation. However for the interpretation of the coefficients the resulting double-logarithmic form is convenient in as far as price influences are concerned, since the estimated coefficients correspond directly to the price elasticity. But for the other variables, the interpretation of the coefficients in the logarithmic specification is much less tangible.

The possibility to replace different coefficients by technical coefficients and thus to get a far less complicate equation compared to equation ( 3-19 ) has been applied by /Schuler et al. 1998b/. There, depending on the question that had to be answered, different technical variables have been replaced by average technical values, e.g. average efficiencies of boilers - depending on their vintage and the energy carrier used - were applied.

More promising in the present context is the use of the specific energy consumption per $m^2$ as explained variable. This is particularly justified since in the two first parts of equation ( 3-19 ) (transmission and airing/ventilation) all terms are at least proportional to the square root of the dwelling space. Also internal and solar gains are more or less proportional to the dwelling space. Hence, together with linearisation one obtains the following equation for the heating energy consumption:

$$e = \chi_0 + \chi_1 V_{Bo} + \chi_2 ET + \chi_3 T_{Bu} + \chi_4 V_{Bu} + \chi_5 R + \chi_6 D + \chi_7 M + \chi_8 z + \chi_9 p + \chi_{10} a + \varepsilon_e \qquad (3\text{-}20)$$

with:

| | |
|---|---|
| $e$ | - Energy per $m^2$ corrected for degree day variations |
| $\chi_0 \ldots \chi_{10}$ | - Regression parameters (possibly vector-valued) |
| $V_{bo}$ | - Vintage boiler |
| $ET$ | - Combination of heating system and energy carrier |
| $T_{Bu}$ | - Type of building |
| $V_{Bu}$ | - Vintage of building |
| $R$ | - Retrofit |
| $D$ | - Dwelling space |
| $M$ | - Ventilation |
| $z$ | - Household characteristics |
| $p$ | - Energy price |
| $a$ | - year |
| $\varepsilon_e$ | - error term |

## 3.4 Investment model

So far the heating energy consumption of an existing building with given characteristics has been subject to explanation. Many policy instruments however attempt to influence the way how buildings are built and – once they are built – retrofitted. The objective of the following section is to present an approach for the modelling of the investment in residential space heating efficiency. With this econometric model developed for the EPISODE project two questions are linked: what factors determine the rate of investment in energy conserving technologies for buildings and what types of policy instruments can accelerate their diffusion?

The chapter starts with some general remarks concerning the investment decision and the investors (section 3.4.1). In section 3.4.2 the specification of a basic econometric model is done including the definition of variables, the discussion of relative importance and completeness of the different variables as well as specifying the mathematical and stochastical form of the relationships between some of the economic variables. As an extension also possibilities to model renovation cycles and corresponding occasions for investment are discussed. Finally the applicability of the developed model given actual data availability will be outlined in section 3.4.3.

### 3.4.1 General approach

Within this section a model is defined which aims at explaining the probability of investment in energy efficiency technologies for buildings. Models with this objective have been developed within the theory on energy conservation respectively efficiency investment. Most of the relevant literature is related to the building sector (commercial and residential), see as examples /Dubin 1985/, /Jaffe, Stavins 1994/, /Hassett, Metcalf 1993/ or /Sutherland 1991/.
A few general points should be clarified right from the beginning:

- Investment decisions on buildings can be connected with the construction of new or retrofitting of old buildings. Measures concerning the heating demand of buildings are often connected with a large construction effort and are followed by an increased value of the building. Energy efficiency investments lower the energy demand of a building through improved insulation, better design etc. Therefore changing an old window by an new one, without a better U-value is regarded as a simple replacement but not as an investment in energy efficiency. In the new construction case the regulation standard forms a (mandatory) basis and the unconstrained investment decision concerns improvements beyond the mandatory standard. Hence energy efficiency decisions in the new construction and the retrofitting case can be modelled structurally similar in one model.
- For purposes of explanation it is supposed that the builder makes a discrete choice of technology, i. e. he decides whether or not to invest in a fixed energy efficiency technology. For this technology the costs and the expected energy savings are known ex ante. One could think of an architect respectively an energy consultant who provides the necessary information for the builder, who decides rationally using the below presented investment calculus.

In as far as the investors are concerned, e. g. according to the German official statistics on building construction the following types of investors can be distinguished:

- private households;
- building companies
  - non-profit building companies;
  - commercial building companies;
  - other companies.
- the public sector (including non-profit organisations);

To show the relevance of the different groups Table 3-9 indicates the shares of building groups in new construction in Germany. From this table the importance of the private households for the building investment respectively the buildings' energy efficiency investment can be seen.

**Table 3-9:** Shares of different groups of builders in the Federal Republic of Germany

| | **Dwellings Built** | **Built by ...** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Private Households** | **Building companies** | | | **Other companies** | **Public companies** |
| | | | **Total** | **non profit companies** | **commercial** | | |
| **Time[a]** | **number in 1000** | **%** | | | | | |
| **1949-1959** | 5312 | 56.3 | 35.7 | 31.6 | 4.1 | 3.7 | 4.3 |
| **1960-1969** | 5588 | 61.2 | 30.9 | 24.9 | 6.1 | 5.5 | 2.4 |
| **1970-1979** | 4863 | 60.3 | 29.5 | 15.4 | 14.1 | 8.2 | 2.0 |
| **1980-1989** | 2980 | 62.9 | 30.6 | 8.5 | 22.1 | 5.1 | 1.4 |
| **1990-1994** | 1834 | 58.9 | 35.1 | 8.7 | 26.4 | 4.3 | 1.6 |
| **1949-1994** | 20577 | 59.8 | 32.2 | 20.6 | 11.6 | 5.5 | 2.6 |

Source: /Ulbrich 1996/ [a]data before 1989 are without the former GDR

For the detailed analysis of policy instruments the distinction of these groups of investors seems useful for the following reasons:

- the instruments may have a different impact on the different groups of investors due e. g. to the owner-tenant dilemma;
- free rider behaviour, investment or liquidity traps may differ between the groups.

### 3.4.2 Basic econometric model specification

In the following a builder is considered who has the option of incorporating a space heating conservation technology into the design of a house at a specified time. So the model considers a simple discrete technology with a fixed amount of energy saving every year. The builder's decision is modelled as corresponding to the following investment calculus. The investor confronts costs and benefits of the investment with the help of yearly annuities. So on the benefit side the yearly saved costs of energy and eventually increased comfort of the house are calculated and on the cost side the yearly payments for the capital loaned for the investment are accounted for. In particular, the investment (in additional energy efficiency in new buildings or in retrofit) happens if:

$$B_1(I) = B(I) + \varepsilon = \delta \cdot \Delta E_{Hap}\left(p_{bt} + TR_1\right)\left(1 + TR_2\right) - \frac{\left(r - r_s\right)}{1 - \left(1 + \left(r - r_s\right)\right)^{-t}}(C - S) + \varepsilon \geq 0 \quad (3\text{-}21)$$

with:

| | | |
|---|---|---|
| $B_1(I)$ | - | Benefit of investment in a fixed technology |
| $C$ | - | Purchase and installation cost of adopting the new technology |
| $\delta$ | - | Discount ($0 \leq \delta < 1$) or premium ($\delta > 1$) to value of energy savings |
| $\Delta E_{Hap}$ | - | Planned reduction in energy consumption per annum through the investment |
| $p_{\mathrm{bt}}$ | - | Real market price of energy before tax |
| $TR_1$ | - | Tax per energy unit e. g. German oil tax |
| $\mathrm{TR}_2$ | - | Tax rate per value unit e. g. VAT |
| $r$ | - | Real market rate of interest |
| $r_{\mathrm{s}}$ | - | Subsidy through interest reduction |
| $t$ | - | Period of credit for investment |
| $S$ | - | Subsidy or tax credit for adopting the technology |
| ε | - | Error term |

Equation ( 3-21 ) corresponds by and large to the benefit-cost ratio used by /Jaffe, Stavins 1994/. However instead of the net present value used by/Jaffe, Stavins 1994/ here the annuity method is used. The two formulations are algebraically equivalent for simple investment alternatives (no reinvestment, no differences in technology lifespans, constant energy prices) as the ones considered here. However, the annuity method stresses that the energy savings have to finance the costs of the investment, presumably mostly financed by a mortgage loan.

On the benefit side of equation ( 3-21 ), first the valuation of the saved costs of energy has to be regarded carefully. In the calculus presented above, the full costs of energy saved are valued by introducing the parameter δ. /Jaffe, Stavins 1994/ suppose that the housing market may discount energy savings because builders cannot represent them credibly and they define this discount factor δ as applied by market to value of energy savings. One should have

- δ < 1 in cases where the dwelling is rented and not the fully investment costs are transferable to the rent (owner-tenant dilemma);
- δ = 1 in cases where the dwelling is self-used and energy costs are fully relevant;

- δ > 1 in cases where the dwelling is self used and a further increase in comfort results from the energy efficiency investment[12].

Second, in the model presented here basically the mortgage interest rate is used as an exogenously given variable. The adequate interest rate to be used is broadly discussed in /Jaffe, Stavins 1994/ and defined there as the discount rate that individuals apply to expected energy savings. What is typically found is that $r$, regarded as individual discount rate, is relatively high (up to 20-30 %). /Sutherland 1991/ and /Hassett, Metcalf 1993/ argue that high discount rates are applied „because energy efficiency investments are irreversible and there is much uncertainty about their payback, given that future energy prices are highly uncertain“ /Jaffe, Stavins 1994, p. 46/. However, /Jaffe, Stavins 1994/ show that there are certain problems with the endogenous determination of discount rates using the individual characteristics of the builder concerning income, liquidity or risk aversion. Additionally some dispute exists in the literature on the applicable market discount rate.

For various investor groups one might expect differences in

- the relevance of the term $\Delta E_{Hap}\left(p_{bt}+TR_1\right)\left(1+TR_2\right)$ valued by δ, e. g. for rented dwellings compared to owner-occupied;
- the average mortgage interest rate $r$ corresponding to differences in the level of liquidity, risk aversion etc.

Hence separate estimation of the equation or the introduction of dummy variables for different investor groups is advisable.

Third, in the model presented here the term $\Delta E_{Hap}$ is a technical term stemming from (renovation or building) plans. It is supposed to be known ex ante, i. e. included in the information bundle concerning the investment. Therefore it is the planned reduction in energy demand for residential space heating instead of the real savings resulting after the implementation..

On the cost side of equation ( 3-21 ) one could include a parameter γ that measures the costs of ignoring regulation, presumably a function of the nature of the standard, the magnitude of penalties, perceived probabilities of enforcement, and likely stigma. In equation( 3-21 ) implicitly a sufficiently high γ is assumed which prompts the builder to meet the standard in the new construction case as it is formulated in the design of the model.

What should be explained is hence the qualitative choice, whether the technology is adopted or not. The model includes stochastic components both because the real investment profitability cannot be fully deduced from sample information and because individual behav-

[12] Another example is the case occurring sometimes in Sweden, that the energy bill in rented dwellings is paid by the owner of the dwelling. In this case one could use a δ ≥ 1 because the investor regards the resulting energy bill and may increase the price for the dwelling in the case of higher comfort.

iour depends on unobserved preferences etc. („personal idiosyncracies“). For the distribution of $\varepsilon$, several assumptions are possible (cf. /Prindyck, Rubinfield 1991/), the most commonly used being the logistic and the standard normal distribution. The logistic distribution leads to the LOGIT model which has the advantage that the probability of investment can be computed explicitly[13].

$$P(I=1)=f(B_1(I)\geq 0)=\frac{e^{\alpha_0+\alpha_1 B(I)}}{e^{\alpha_0+\alpha_1 B(I)}+1} \qquad (\text{3-22})$$

with:

| | | |
|---|---|---|
| *P (I)* | - | Probability of investment |
| e | - | Base of natural logarithms |
| $\alpha_0, \alpha_1$ | - | Estimation parameters |

The relationship between $B_1(I)$ and the investment probability is non-linear, consequently the impact of a policy variable depends on the current level of the other model variables. Thus the basic model is fully specified and allows in principle the estimation and simulation of different policies to stimulate investment.

As an extension to the basic model the modelling of the timing of investments should be included. In the basic model the investment decision may occur at any point in time, if the net benefit $B_1(I)$ becomes positive. In reality some points in time are certainly privileged for investing in energy efficiency. These are the moment of construction of a new building and the moments when building components have to be replaced anyway.

Thus the probability of investment may not only depend on the investment calculus but also on other factors. These could be included in the basic model by reformulating it as a “when and whether” model. Then in particular the costs for an energy efficiency measure like 10 cm wall insulation should depend on the point in time considered: at the construction of the building the additional costs are low, after the construction the costs are much higher, given that the plaster and the painting have to be destroyed first and reapplied after the insulation works. Later, when the building shell is refurbished anyway, the costs for insulation are lower again. I. e. if the insulation is not applied during construction or during cyclic renovation activities good opportunities for energy efficiency improvements are lost.

Another possibility is to model the occurrence of a decision on energy efficiency investment as a separate probability:

$$P(I_0=1)=f(v,z_4,i,s,p_{at}) \qquad (\text{3-24})$$

with:

$I_0$ - Decision on investment in energy efficiency

13 The standard normal distribution yields so-called PROBIT models. Here the probability mass at the boundaries is somewhat smaller than for the LOGIT models. Yet in most practical applications no substantial differences are found (cf. /Maddala 1993/).

$v$ - Absolute value of the difference between age of a component and its normal lifespan
$z_4$ - Income
$i$ - Average interest rate of alternative investment possibilities
$s$ - Signalling through subsidies
$p_{at}$ - Signalling through energy prices

By specifying a LOGIT-model with linear arguments one obtains:

$$\ln\left(\frac{P(I_0=1)}{1-P(I_0=1)}\right)=\alpha_0+\alpha_1\cdot v+\alpha_2\cdot z_4+\alpha_3\cdot i+\alpha_4\cdot s+\alpha_5\cdot p_{at} \qquad (3\text{-}25)$$

In this formulation besides the position relative to the renovation cycle personal attributes like income (one could think also of number of persons per household, etc.) determine the decision probability. Also policy variables are potentially relevant here but in a slightly different manner. Subventions or taxes on energy may act as a signal to the builder that a public interest exists to invest in energy efficiency. So the overall propensity to invest could be increased given an incentive to meet the public wants. Additionally the average interest rate for alternative investment possibilities is important when envisaging an investment in energy efficiency of buildings. Depending on the interest rate the builder decides whether there are higher rated alternatives than the investment in energy efficiency[14].

### 3.4.3 Application possibilities

Problems with the theoretical model occur if the description of the investment process uses variables that are either not directly observable or not asked by the official statistics or surveys. In Table 3-10 the variables which are used in the model are listed and it is indicated whether a proxy has to be chosen or not.

[14] To describe this investment choice problem the capital asset pricing model (CAPM) may be used (cp. /Sutherland 1991/).

**Table 3-10:** Variables to specify the investment model

| Item | Variable | Influencing factors | Observable/Possible proxies |
|---|---|---|---|
| Investment | $I$ | Explained variable | Few direct observations – if at all only cumulative status (investments up to now or investments in the last 10 years) |
| Cost of technology | $C$ | Available technologies<br>Product costs<br>Installation costs<br>Standards | If at all only observable for typical buildings |
| Value of energy savings | $\delta$ | Market prices for renting house restricted by laws on rent<br>Market prices for selling house<br>Individual comfort | Allowed rent raising after investment in energy efficiency<br>Observable<br>Market value selling house |
| Quantity of reduction in energy used | $\Delta E_{Hap}$ | Available technologies | If at all only observable for typical buildings |
| Expected market price for energy before tax | $p_{bt}$ | | Current prices as proxies (assumption of myopic expectations) |
| Tax rate | $TR$ | VAT<br>Energy taxes | Observable |
| Real market mortgage rate of interest | $r$ | | Observable |
| Subsidy or tax credit | $S$ | Subsidy programs | Observable |
| Decision on investment | $I_0$ | Explained variable | No direct observations in official statistics |
| Difference age/normal replacement by a building component | $v$ | Vintage of component<br>Replacement cycle | Vintage of building<br>Indications from technical guidelines |
| Average interest rate of alternative investment possibilities | $i$ | | Observable |
| Signalling through subsidies | $s$ | Number of subsidies<br>Budget of subsidies | Observable |
| Signalling through energy prices | $p_{at}$ | Variation of energy prices | Observable |

The basic problem that occurs for the application of the developed model is that observations on investment in energy efficiency are hardly available in official statistics at a micro level. Even less can be said on whether "decisions on investment" (variable $I_0$) are taken. Also for other variables some observational problems occur.

The policy variables taxes, standards and subsidies are directly observable or calculable, this holds also more or less for variables that result from market processes as the mortgage interest rate, the purchasing costs of insulation components or the rents and selling prices of houses respectively dwellings.

Yet data availability is problematic e. g. for Germany in the following points:

- Whereas building investment is covered by the German statistic this says nothing about the spending on proper energy efficiency investments. So the number of cases or the sum of investment for energy efficiency improvements is not observable (alternative: estimation of typical cases);

- The time and kind of the replacement of a component is not covered by the official statistic. What is available are typical replacement cycles which are estimated on theoretical grounds and some empirical observations;
- The valuation of the energy savings respectively the increased comfort either by the houses which are rented off or are owner-occupied is not observable directly. For the rented house some proxies using the underlying laws on rent could be determined, but the extension of the model using the valuation factor $\delta$ seems empirically difficult;
- For further definition of internal discount rates applied to the investment decision far more information about risk expectations and liquidity conditions of the groups of investors is necessary (problems with availability, so this aspect must be specified mainly using theoretical assumptions).

Given these data restrictions unfortunately the investment model may not be tested fully in the empirical analysis. In particular the modelling of the decision on investment is hardly applicable. For the investment, especially in retrofit, only simplified models may be tested explaining not the investment itself but the retrofit status by characteristics of the building and the owner.

### 3.5 Estimation methods

The econometric model developed in section 3.3 and section 3.4 is divided into two parts, a first model reflecting technical features of the building and the utilisation intensity concerning residential space heating and a second model explaining investment decisions of households and other investors in heating energy conservation measures. The models are linked so far through the investment decisions which are determined in the investment model and used after this as an input in the model on technical features and utilisation patterns to determine the energy demand of the improved house (cf. Figure 3-2 upper left side).

As shown in the previous sections this two step approach is theoretically convincing. Causal relationships become clear and a lot of hypotheses are pointed out. Also the approach is in principle feasible in an international context despite a few issues of the model which hinder an equal use in all countries e. g.

- solar gains are difficult to compare and
- in some countries using annuities as bases for the investment calculus is not very common.

However, applications of the model crucially depend on available data. Given the limited data availability for the investment model the focus of the empirical investigations must be on the energy use equation. The policy instruments which act on the investment decision (subsidies, prices) can also be included in the specification of the energy consumption model, yielding a "one step" or "reduced form" model (cf. Figure 3-2). However the results of such an analysis without an analysis of the underlying causal relationship have to be interpreted with caution. Both the one step and the two step approach (cf. Figure 3-2) allow to identify general effects of politics, but the two step approach provides an improved understanding of selected mechanisms of policy instruments influencing the investment behaviour.

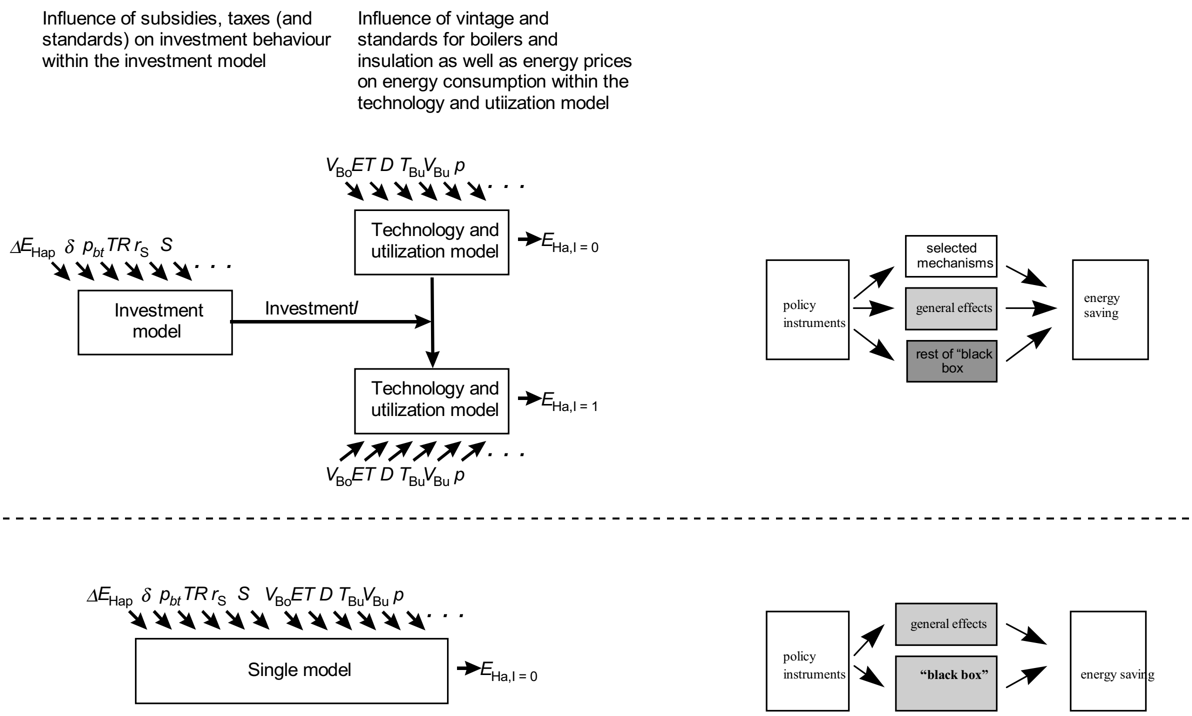


**Figure 3-2:** Difference between two step and one step approach

The focus of the empirical work has therefore been on the estimation of the (extended) energy consumption equation using adequate estimation techniques. The investment model has also been estimated for countries were corresponding data were available using conventional Maximum-Likelihood-estimators for Logit-Models. Given the limited data availability no attempt has been made to estimate both equations simultaneously accounting for possible covariances in the error terms.

The major econometric model to be estimated is thus an energy demand equation for the total consumption of energy for space heating at the building level conditional on the type of heating system present in the building and other building characteristics. If observations of energy consumption are available for the same buildings at different points in time (panel data), then particular panel data estimation techniques may be employed (cf. e.g. /Baltagi 1995/). These estimation techniques allow improved accuracy and the exclusion of some potentially relevant estimation biases that can not be tackled by ordinary least squares (OLS) regressions. In the following the basic principles of the employed techniques are outlined, more detail may be found in the national working papers /Leth-Petersen,Togeby 1999/, /Kjellsson, Leth-Peterson 1999/.

The major point that can be accounted for through panel estimation techniques is the possible simultaneity of switching heating system (or other building retrofits) and the energy consumption. The possible simultaneity between initial choice of heating system and demand for energy (cf. /Dubin, McFadden 1984/) is not considered in the following due to lack of appropriate data.

The short run demand for energy (cf. equation (3-20) in section 3.3) can be written, accounting for both variations in time $t$ and variations over buildings $i$ in short:

$$e_{it} = \beta_1{}^j d_{it}{}^j + \beta_2 X_t + \mu_i + u_{it} \qquad (3\text{-}20)$$

with:

| | |
|---|---|
| $e_{it}$ | - Energy per m$^2$ corrected for degree day variations (possibly in natural logarithms) |
| $i$ | - index building |
| $t$ | - index observation year |
| $\beta_1^j$ | - Regression parameter heating system $j$ |
| $d_{it}^j$ | - Dummy variable heating system $j$ |
| $\beta_2$ | - Regression parameters time-variant variables |
| $X_t$ | - Time-variant variables (e.g. energy prices) |
| $\mu_i$ | - fixed effect, building $i$ |
| $\varepsilon_{it}$ | - general error term (random mean-zero, symmetric distribution) |

$d_{it}^j$ is a vector of dummy variables taking the value one at the point when the building switches to heating system $j$ and throughout the observation period. If the coefficient of the switching dummy, $\beta_1^j$, is divided into a mean component and a random component, $\beta_1{}^j = \overline{\beta}_1{}^j + \beta_{i1}{}^j$, equation ( 3-20 ) may be rewritten as

$$e_{it} = \overline{\beta}_1{}^j d_{it}{}^j + \beta_2 X_t + \mu_i + v_{it} \qquad (3\text{-}21)$$

where $v_{it} = \beta_{1i}{}^j d_{it}{}^j + u_{it}$. Estimation of ( 3-21 ) using OLS is likely to yield biased estimates. This is due to the possibility of $E[X_t\, \mu_i] \neq 0$ or $E[d_{it}^j\, \mu_i] \neq 0$. Further, it is possible that $E[X_t\, v_{it}] \neq 0$ and $E[d_{it}^j\, v_{it}] \neq 0$. $E[X_t\, \mu_i] \neq 0$ or $E[d_{it}^j\, \mu_i] \neq 0$ causes the conventional fixed effects problem in panel data analysis where as $E[X_t\, v_{it}] \neq 0$ or $E[d_{it}^j\, v_{it}] \neq 0$ causes a more general problem of endogeneity. Note, that $E[d_{it}^j\, v_{it}] \neq 0$ if the decision to change the heating system and the decision to consume energy for space heating are simultaneous ones.

Consider the following model describing buildings that have *not* changed heating system

$$e_{it} = \beta_2 X_t + \mu_i + u_{it} \qquad (3\text{-}22)$$

Assuming for the moment that $E[X_t \mu_i] \neq 0$, ( 3-22 ) can be estimated as a fixed effects model /Baltagi 1995/. Using the so-called within transformation implies estimating

$$\tilde{e}_{it} = \beta_2 \tilde{X}_t + \tilde{u}_{it} \tag{3-23}$$

However, for buildings changing heating system the model becomes

$$e_{it} = \bar{\beta}_1^{\,j} d_{it}^{\,j} + \beta_2 X_t + \mu_i + v_{it} \tag{3-24}$$

where $d_{it}^j = 1$ from the point in time of the change of heating system and hereafter, and $d_{it}^j = 0$ otherwise. Within transforming ( 3-24 ) yields

$$\tilde{e}_{it} = \bar{\beta}_1^{\,j} \tilde{d}_{it}^{\,j} + \beta_2 \tilde{X}_t + \tilde{v}_{it} \tag{3-25}$$

If in this model, $E\left[\tilde{d}_{it}^{\,j} \tilde{v}_{it}\right] \neq 0$ and/or $E\left[\tilde{X}_t \tilde{v}_{it}\right] \neq 0$, estimates of $\left(\bar{\beta}_1^{\,j}, \beta_2\right)$ will still be biased. However, noting that ( 3-22 ) still describes the buildings that change the heating system, before they change, and that ( 3-24 ) describes the buildings after the change, the problem of endogeneity can be addressed by estimating two fixed effects for buildings that change heating system.

This is done by splitting the series of observations for buildings that change the heating system in to two separate series for which individual specific intercepts are estimated. In this way individual intercepts for buildings that do not change and buildings that change observed *before* they change are given by $\hat{\alpha}_i = \mu_i$, and individual intercepts for buildings that change the heating system after they change are given by $\hat{\alpha}_i = \mu_i + \bar{\beta}_1^{\,j} d_{it}^{\,j}$. This amounts to estimating ( 3-23 ) for buildings not having changed the heating system and buildings changing the heating system *before* they change, and ( 3-26 ) for buildings changing the heating system *after* they have changed.

$$\tilde{\tilde{e}}_{it} = \beta_2 \tilde{\tilde{X}}_t + \tilde{\tilde{v}}_{it} \tag{3-26}$$

where ( 3-26 ) is the within transformed version of ( 3-25 ) including additional individual intercepts.

One drawback of estimating a fixed effects model is that applying the within transformation it is not possible to obtain parameter estimates of time invariant variables. These estimates are of great importance in this analysis because important policy variables are time invariant. One solution is to compute all the fixed effects from the estimation of ( 3-20 ) by $\hat{\alpha}_i = \overline{e_{i.}} + \overline{X_{i.}\beta}$ , where $\hat{\alpha}_i = \mu_i$ is the fixed effect for individuals that do not change at all and individuals that change heating system in the observation period - before they change - and $\hat{\alpha}_i = \mu_i + \bar{\beta}_1^{\,j} d_{it}^{\,j}$ is the fixed effect for individuals that change, after the change. Having computed $\hat{\alpha}_i$, it is in turn regressed on the time invariant variables that were omitted from the within transformed regression of ( 3-20 ):

$$\begin{aligned}\hat{\alpha}_i &= \gamma X_i + \eta_i^c + \eta_i \\ &= \gamma X_i + \eta_i^* \quad , \qquad \eta_i^* = \eta_i^c + \eta_i\end{aligned} \tag{3-27}$$

Where $\eta_i^c$ is the unmeasured individual deviations from the mean effects estimated by $\gamma$ and $\eta_i$ are random errors. The regression yields unbiased estimates if indeed it is deviations from the mean effect that have caused the fixed effect. Unbiasedness requires $E\lfloor \tilde{X}_{it}\eta_i^* \rfloor = 0$ and $E\lfloor X_i\eta_i^* \rfloor = 0$, i.e. that $\eta_i^*$ be uncorrelated with the within transformed time varying variables and the time invarint variables /Moffitt 1993/. The first requirement is satisfied by construction whereas the latter cannot be tested without candidate instruments, however not available within the used data bases.

# 4 Empirical results

This chapter contains the empirical results of the regression analyses and the calculated results of the building model. The main focus is on the empirical results starting with the used data (cf. section 4.1). The empirical results are discussed in section 4.2 (energy use equation) and 4.3 (investment equation). Section 4.4 gives an overview over the building model and the calculated results. Finally a comparison of empirical and calculated results is shown in section 4.5.

## 4.1 Data for the empirical analyses

The analyses for the participating countries are based on different data bases. The data bases differ in the size, the observed years, and partly in the observed building and household characteristics. This section gives a short overview of the different national data bases. The choice of the variables and the results of the estimated coefficients of the national analyses is of course depending on the available data. Further it is not possible to make a panel data analysis, when only one year is observed.

*The Netherlands*

The Dutch analysis is based on data from the annual Budget survey, carried out by Statistics Netherlands[15]. Six consecutive years have been observed (1990-1995). The budget survey contains a lot of information like the energy use, building characteristics, household characteristics and many more. The average sample size of the survey is around 2000 households. About one third of the households have participated for two or three consecutive years.

The used subsample of the budget survey contains only households using gas as a heating fuel. Households that moved during the observation year have been excluded. Outliers with an energy use for space heating of less than 50 kWh/m$^2$ or more than 500 kWh/m$^2$ have also been excluded. The total amount of the remaining observations is 9449.

*Germany*

The German analysis is based on the building and dwelling sample made by the federal statistical office. In 1993 1% of the German dwellings have been observed. The building and dwelling sample contains information about building and dwelling characteristics, household characteristics, the energy use and many more. A 10% sample (34630 buildings) of the building and dwelling sample was ordered to use this data for the analysis. The number of observations decreased to 16530 when observations with missing values (especially roomwise or floorwise heating) and outliers (<50 kWh/m$^2$, >500kWh/m$^2$) have been removed. It is not possible to use the German data for a panel data analysis, because the dwellings have only been observed for a single year.

*France*

The French investigations are based on surveys made by CEREN. The dwellings have been observed for eight years from 1990 to 1997. The total number of observations used in the analysis is 13727. The data base contains information which is similar to the Dutch and German data bases.

*Sweden*

Statistics Sweden collects survey data for single family dwellings (since 1977) and multi-family dwellings (since 1976) separately. In order to use as much panel data as possible, a selection was made for the multi-family data. Panel data were available for one owner type, a housing co-operative, representing dwellings for about 10% of the Swedish population. The dwellings have been observed from 1982 to 1997. The number of observed dwellings increased from 2300 for the year 1982 to 4000 for the year 1997.

For single family dwellings information from about 6000 households are collected by Statistics Sweden. Normally the sample surveys use the same samples for about three years. Two subsamples have been used in the Swedish analyses for single family dwellings: 1977-1980 and 1992-1994.

The collected information of the Swedish surveys is similar to the other countries. But there are some differences due to the data base. It is not possible to analyse the influence of the owner type on the energy demand for space heating, when only one owner type is observed in the database.

*Denmark*

The sample to be analysed in Denmark is taken from a survey which is part of a consultancy scheme, called VKO. The survey observed the period from 1984 to 1995 and contains 4008 multi-family buildings. The buildings have been observed 7,5 time on average. The survey contains information about the energy use, the energy carrier and heating system, the type of owner and more. More information about building characteristics is taken from the building register (BBR). However no information on the occupants is available.

The data bases of the participating countries show a lot of similarities. Often the energy use includes the energy use for domestic hot water, which has to be subtracted from the energy use to get the energy use for space heating. Further data have been used to correct climatic

[15] These data were made available by WSA/NWO.

influences in the data base. Figure 4-1 shows the mean energy use for space heating in the different samples compared to the national average observed in 1995. For Sweden the mean energy use is shown separate for multi-family buildings and single-family buildings corresponding to the different samples used. For Germany, Denmark and Swedish multi-family buildings the average consumption in the sample deviates 10 % or less from the national average ( cf. section 2.1). For Germany the sample consumption is presumably somewhat higher than the national average since dwellings with single ovens and correspondingly lower consumption are not included in the sample. For Denmark the inverse holds since the sample contains only multi-family dwellings which consume less on average. The consumption is far lower in the French sample (189 kWh/m$^2$ for the national average, 124 kWh/m$^2$ in the sample) compared to the respective national average caused by the higher number of new dwelings included in the sample. For The Netherlands and Swedish single-family buildings and multi-family buildings the average consumption is far lower compared to the sample. This is at least in Sweden due to the difference between the years of observation for the samples (SFB: 1977-1980 and 1992-1994; MFB: 1982-1997) and the year of observation of the mean values (1995). The differences in the mean energy use for space heating between the participating countries may be caused by factors like climatic differences, the observed building types, the number of introduced building codes, the observed energy carriers and heating systems and others. The role of these factors has already been discussed in chapter0 and will be further discussed in the following.

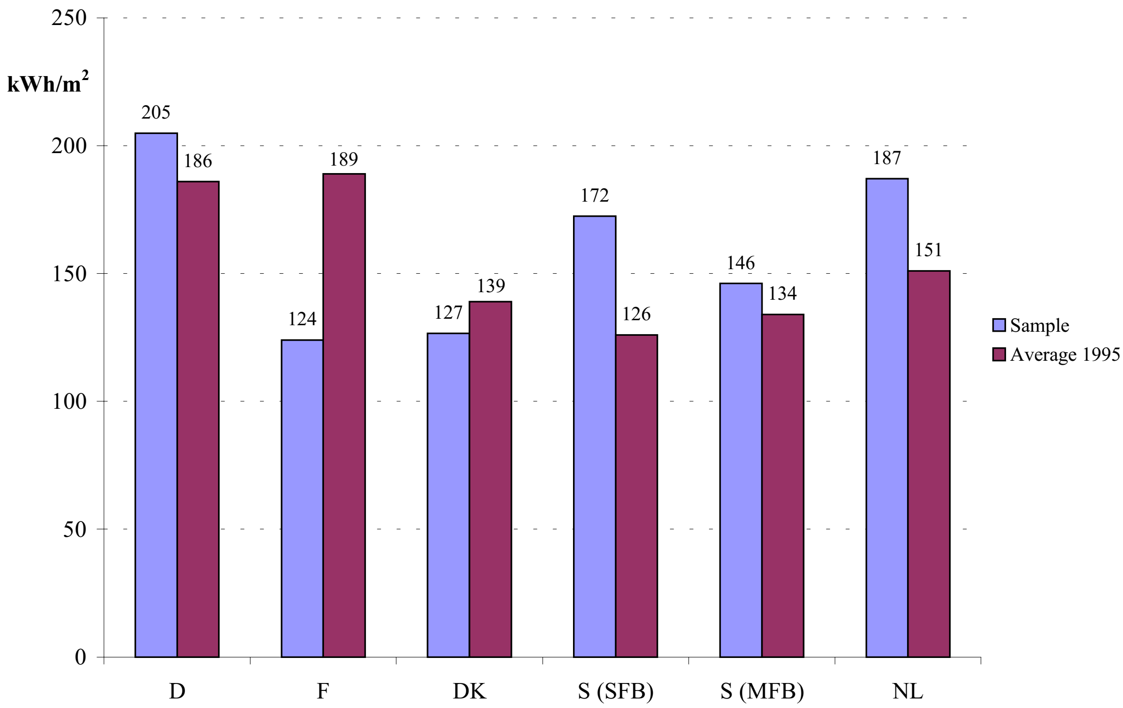


**Figure 4-1:** Mean energy use for space heating

## 4.2 Estimation results for energy use

This section shows national differences and similarities in the results of the regression analysis. The energy use equation (3-20) in chapter 0 has been used as basis to explain the energy use for space heating. The model structure is linear and the explaining variables are limited to those which are observable in the national data bases. In the regression analysis the coefficients of independent variables like the heating system, the energy carrier, vintage classes of heating systems and buildings, and many more have been estimated. The estimated coefficients shown in the following are absolute values of the energy use. These coefficients are easier to understand than the logarithmic values which are also shown in the national working papers.

The energy use equation has been estimated using ordinary least squares (OLS) regressions in the case of France, The Netherlands and Germany. For Denmark and Sweden the panel data structure has been exploited using a fixed effects model. This stochastic model allows to account better for individual unobserved characteristics of buildings exploiting the repeated observations in panel data.

It is important that the included variables fit well to the available data bases. Due to the differences of the available data in the participating countries the independent variables have been adapted. The results of the Dutch, French, Danish, Swedish and German analyses have been classified in the following categories in order to structure the comparison:

- Vintage class effects,
- Building types,
- Energy carrier / heating system,
- Retrofit / renovation,
- Other building characteristics,
- Owner types,
- Occupants characteristics,
- Price effects,
- Subsidies and other instruments and
- Time trend.

The used variables differ partly between the participating countries, therefore it is not possible to compare all variables for each country. Further it is not easy to categorise all estimated variables. Some variables contain so much information, that it is possible to group these variables in two or three of the chosen categories. The shown coefficients in linear scale express changes in energy use for space heating (in kWh/m$^2$) compared to the chosen reference case. Significant variables at 5% level are signalled by an asterisk.

The explaining power of the models must be limited because it is not possible to include all variables in the equations. In particular there are also important unobserved variables like occupant behaviour, specific building geometry and building materials. Table 4-1 shows the $R^2$-values as a measure for the explaining power of the national regressions.

**Table 4-1:** $R^2$-values

| Country | D | DK | F | NL | S (SFB) | S (MFB) |
|---|---|---|---|---|---|---|
| $R^2$ | 0.190 | 0.664[a] | 0.516 | 0.247 | 0.471[a] | 0.536[a] |
| [a] second stage of the panel data analysis | | | | | | |

### 4.2.1 Vintage class effects

By looking at the vintage class effects the impact of standards can be evaluated. The influence of vintage classes on the energy demand for residential space heating is shown in Figure 4-2. In all participating countries introduced standards led to a reduction of the energy demand for residential space heating. Most standards concerning the insulation of buildings were introduced in the 1970s for the first time (cf. chapter 0). Most decrees and building codes concerning the insulation apply to new constructions, some likewise apply to extension of older buildings.

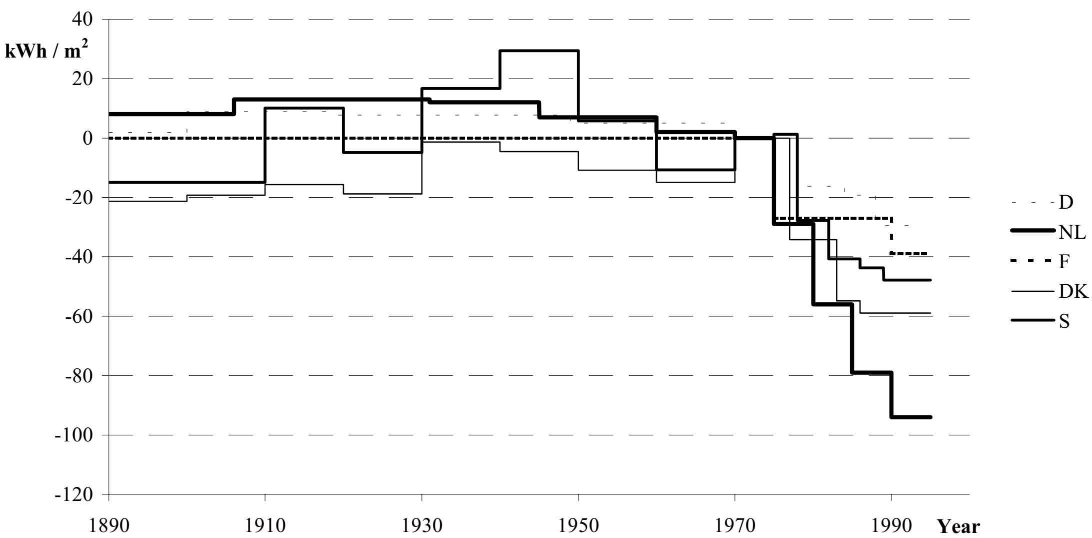


**Figure 4-2:** Vintage class effects (buildings) (deviations from vintage 1970-1975)

The graphs show an increase of the energy demand for buildings built before the end of the second world war especially in Sweden and Denmark. In the post war period the energy consumption decreased somewhat in most countries. The reduction of the space heating demand is significant. The results concerning the vintage classes before the 1970s should however not be overinterpreted because often the estimated coefficients are not significant. After the first oil price crisis and the subsequent tightening of standards however significant decreases are observed.

The strongest reduction can be observed in the Dutch case (–94 kWh/$m^2$ since the beginning of the1970s), followed by the Danish (-59 kWh/$m^2$), Swedish (-48 kWh/$m^2$), French (-39 kWh/$m^2$) and German (-29 kWh/$m^2$) results. The effect of the tightened standards appears hence clearly in the vintage classes but there might be a difference between the observed energy reduction and the expected energy reduction according to building models.

### 4.2.2 Building types

The influence of the building/dwelling type has been analysed in The Netherlands, France and Germany. The Dutch reference building type is an attached single family house, which is compared to a detached single family house, apartments and the category “other types”, including farmhouses and houseboats. All analysed building types of the Dutch investigation use the same energy carrier – gas. The detached single family houses use substantially more energy for space heating than the reference category (attached single family houses). The same result is observed in the French investigations. The estimated coefficients are shown in Table 4-2. The other building types also show a higher energy consumption, but still lower than the detached single family houses. Apartments require the lowest energy consumption for space heating. This result is also observed in France and Germany. In The Netherlands the energy consumption between detached single family houses and apartments differs by 88 kWh/$m^2$. In the other countries the difference is smaller but still all building type variables show significant coefficients. The building type has hence a strong impact on the energy use.

**Table 4-2:** Influence of the building type

| *in kWh/m²* | **NL** | **D** | **F** |
|---|---|---|---|
| single family houses, detached | +57.0* | (reference) | +19.9* |
| single family houses, attached | (reference) | | (reference) |
| apartments | -30.8* | -29.5* | -27.6*[a] |
| other types | +41.5*[b] | -12.9*[c] | |

[a] average of apartments oriented north and south [b] farmhouses, houseboats, ... [c] farmhouses

### 4.2.3 Energy carrier / heating system

Another relevant influence on the energy use for space heating is the choice of the energy carrier and the heating system. Table 4-3 shows the results on the influence of energy carriers and heating systems. Depending on the nationally prevailing energy carriers in each country different energy carriers have been observed in the sample. In particular in the Dutch investigations only one energy carrier is observed – gas. The reference case of the heating system is a central heating system. The alternative, local gas fired ovens, leads to a decrease in energy use for space heating by nearly 40 kWh/m$^2$. The estimated coefficient is significant. The higher consumption of the gas fired central heating may be caused by larger losses in the heating system but especially by larger heated areas in centrally heated buildings.

For the other countries the energy carriers oil, gas, electricity and district heat are mostly present. However district heat is missing in France, gas is absent in Sweden and electric heating is not observed in Germany and Denmark. In all countries homes heated with electricity (except Swedish multi-family buildings) or district heat are found to have lower energy consumption than those with oil-fired and gas-fired heatings. This is to a large extent due to the fact that district heat and electricity can be converted to useful energy without important losses, whereas for oil and gas substantial conversion losses occur. Furthermore electric heating is often done by individual, locally regulated radiators, which leads to smaller heated areas on average (as for local gas-heating, cf. above). However for France and the Swedish single-family houses the observed decreases in consumption for electrically heated houses are so large, that other explanations have also to be considered. One reason is that higher insulation requirements are stipulated or higher insulation efforts (due to the higher price per kWh) are undertaken in the case of electrically heated homes. Another relevant factor might be self-selection corresponding to climatic differences. Both in Sweden and France the climate is much warmer in the south than in the north. Since regional climatic differences are only accounted for by broad zones (3 in France and in Sweden), the unobserved climatic variations correlate with the use of electric heating and consequently biases the corresponding regression coefficients.

The high energy consumption for electrically heated multi-family houses in Sweden is not in conformity with the results for the single-family houses and the French results. However this is only a small part of the sample (1.4%) and within this fraction buildings in cold zones are overrepresented. Thus an inverse sample selection is apparently existing, due to the unavailability of district heating in the north. The results should therefor not be overinterpreted. Further results are obtained for the use of wood respectively the existence of an open fireplace. For Germany the decrease in the consumption of fossil fuels or district heat is found to be significant although limited. In France and Sweden dwellings heating additionally with wood are found to have a somewhat higher overall consumption than the dwellings without, due to the low efficiency of open fireplaces and many wood ovens.

**Table 4-3:** Influence of energy carriers / heating systems

| *in kWh/m²* | NL | D | F | S (SFB) | S (MFB) | DK |
|---|---|---|---|---|---|---|
| **oil, central heating** | - | (reference) | (reference) | (reference) | (reference) | (reference) |
| **gas, central heating** | (reference) | +30.0* | -48.2* | - | - | +18.1* |
| **district heat** | - | -37.2* | - | -90.1* | -28.7* | -52.4* |
| **electricity** | - | - | -121.6* | -61.2* | 57.1* | - |
| **local heating** | -39.7* | - | - | - | - | - |
| **additional use of wood** | - | -8.6*[a] | +10.4[b] | +8.5[c] | - | - |

[a] decrease in consumption of gas, oil or district heat
[b] difference in total energy consumption of dwellings with electricity and wood compared to dwellings with only electricity
[c] average difference of energy consumption of dwellings with use of wood in addition to electricity, oil or/and district heat compared to dwellings without wood use

Another interesting effect has been analysed in Denmark and Sweden – effects linked to the switch of the energy carrier. The Swedish and Danish databases allow these investigations because the same dwellings have been observed for several years. The results are shown in Table 4-4. It turns out that the consumption of these dwellings does neither before nor after the energy carrier shift differ significantly from the consumption of the same heating systems in the case of no energy carrier shift (cf. Table 4-3).

**Table 4-4:** Influence of changes in the energy carrier

| **Country** | **Variable** | **Coefficient** *in kWh/m²* |
|---|---|---|
| **S (MFB)** | oil-district heat-before | 17.7* |
| | oil-district heat-after | -1.0 |
| | oil-not central-before | 16.9* |
| | oil-not central-after | 51.3* |
| **DK** | oil-gas-before | 46.8* |
| | oil-gas-after | 59.1* |
| | oil-district heat-before | 45.4* |
| | oil-district heat-after | -8.7* |

The effects of vintage classes of boiler/heating systems have been observed in France and Germany. Figure 4-3 shows the results. The heating systems of the observed dwellings have been divided in to three vintage classes, heating systems younger than five years, five to fifteen years old systems and systems which are older than fifteen years. The estimated coefficients fit well to the expectation that elder heating systems use more energy than younger systems. In France these effects have been observed for oil-fired and gas-fired heating systems separately. The coefficients for gas-fired heating systems show a difference between the youngest and oldest class of 26 $kWh/m^2$. The observed difference for oil-fired heating systems is a bit smaller, only 18 $kWh/m^2$. The estimated coefficients of the German analysis include only oil-fired heatings. The observed difference between the youngest and oldest class (10 $kWh/m^2$) is rather small compared to the French results. Between the heating systems younger than five years and heating systems which are five to fifteen years old, no difference in the amount of energy use for space heating has been observed. In the Dutch, Danish and Swedish data the vintage of the boiler is not observed. Yet a time trend is included which captures at least partly the impact of boiler efficiency improvements (cf. section4.2.10).

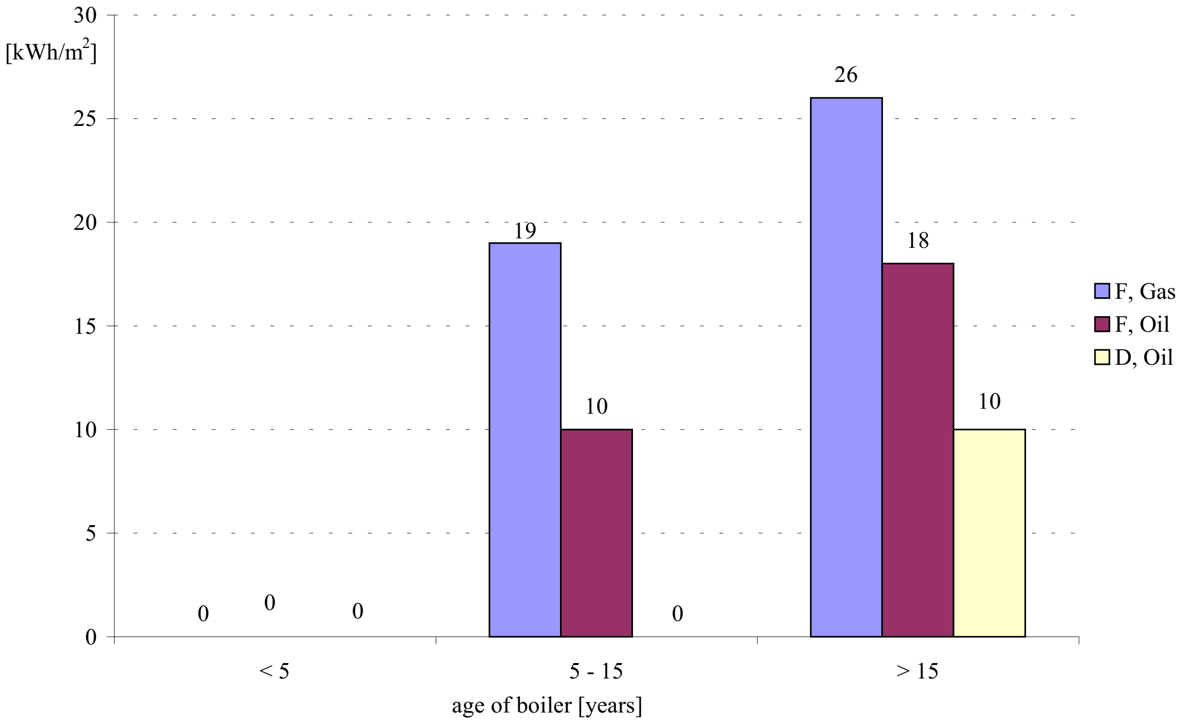


**Figure 4-3:** Influence of the vintage classes of boiler

### 4.2.4 Retrofit / renovation

Renovation of buildings and dwellings offers a possibility to reduce the energy consumption for space heating. Table 4-5 shows the results for the analysed variables concerning retrofit.

Insulation measures have been observed in all countries except Denmark. Retrofitting of insulation shows the highest reduction of all measures concerning retrofit or renovation. Insulation measures have been analysed in The Netherlands and Germany more detailed. Wall insulations offers a higher reduction compared to roof or floor insulation. Most observed coefficients concerning insulation are significant negative. For France and Swedish single-family buildings the different insulation measures have been summarised in single coefficients.

Retrofit of insulation windows has been analysed in The Netherlands, Sweden and Germany. The Dutch significant coefficient shows a high reduction compared to the Swedish coefficients showing a small reduction and the German coefficient which is insignificant and positive.

The change of the dwelling design is included in the variable called "major renovation undertaken". This variable summarises several measures (e.g. mechanical ventilation in France) but the significant coefficients show only a small reduction.

Additional building features like the presence of thermostats or outside temperature sensors have been analysed in Germany. The presence of thermostats shows a significant reduction of the energy use. The presence of the temperature sensor shows a negative but insignificant coefficient.

**Table 4-5:** Influence of retrofit

| *in kWh/m²* | **NL** | **D** | **F** | **S (SFB)** | **DK** |
|---|---|---|---|---|---|
| Wall insulation retrofitted | -16.0* | -9.8* | -16.5* (-21.8*)[a] | -6.2* | |
| Roof insulation retrofitted | -5.8* | -5.4* | | | |
| Floor Insulation retrofitted | -3.7 | | | | |
| Insulation windows retrofitted | -16.9* | 2.9 | | -3.5* | |
| Major renovation undertaken | | -8.5* | -10.4*[b] | -3.6* | -6.8* |
| Thermostat added | | -7.6* | | -1.9* | |
| Temperature sensor added | | -0.4 | | | |

[a] with mechanical ventilation
[b] mechanical ventilation added

### 4.2.5 Other building characteristics

In the national analyses some more variables have been defined that describe the general building characteristics. It is difficult to attach these additional variables to one of the previous categories like building types, retrofit or vintage classes. For that reason the remaining variables were grouped in this category. These variables are the dwelling space in the case of The Netherlands, France and Germany and the number of flats for Sweden and Denmark. Additionally the number of floors has been included in the Danish analysis. The results are shown in Table 4-6.

**Table 4-6:** Influence of building characteristics

| Country | Variable | Coefficient *in kWh/m²* |
|---|---|---|
| NL | Dwelling space in $m^2$ | -0.7* |
| D | Dwelling space in $m^2$ | -0.003* |
| F | Dwelling space in $m^2$ | -0.4* |
| S | Number of flats | -0.011* |
| DK | Number of flats | 0.1* |
| | No. of floors not registered | 38.7* |
| | Ground floor only | 37.3* |
| | First floor | 22.1* |
| | Second floor | 15.8* |
| | Third floor | 4.4* |
| | Fourth floor | -1.5 |
| | Fifth floor | -4.7 |
| | More than 7 floors | -4.1 |

The results show that the energy use decreases with growing dwelling space. This can be explained as a consequence of a more compact building design: The shell-surface-to-floor-surface-ratio is lowered when the dwelling space increases.

The estimated coefficients for the influence of the influence of the number of flats show different signs. In the Swedish case energy use decreases with the number of flats, also related to a more compact building design. The Danish coefficient on the contrary indicates a raising energy use by a raising number of flats in the building. However the number of floors has also been included in the Danish investigation. The number of floors as the major indicator of compactness has a negative influence on the energy demand for all buildings with less than four floors, the remaining coefficients are not significant.

### 4.2.6 Owner types

The ownership status and/or the types of owners have been analysed in most participating countries. The estimated regression coefficients for the variables describing different types of ownership are shown in Table 4-7 and Table 4-8. Whether the dwelling is owned was analysed in the Dutch, the German and the French investigation. The estimated Dutch coefficient is significant and shows a positive influence on the energy demand for space heating, which means a higher energy consumption by around 7 kWh/$m^2$. Also for France the estimated regression coefficient shows that in rented dwellings less energy for space heating (-4 kWh/$m^2$) is used. In the German analysis the influence of rental status on the energy use has been analysed separately for single- and multi-family buildings. The owner-occupied single family buildings use more energy (+7 kWh/$m^2$) than rented single family buildings. The opposite occurs for multi-family buildings. In this case owner-occupied dwellings use less energy (-6 kWh/$m^2$) for space heating. Both German coefficients are significant, but only the result for the single-family dwellings is in conformity with the French and Dutch results.

In the Danish and the German analysis nine owner types have been distinguished. The reference category is formed by dwellings owned by a private person. In the German case only one of the remaining regression coefficients is significant. In dwellings owned by a dwelling company significantly more energy for space heating (+8 kWh/$m^2$) is used than in dwellings owned by a private person. The results for the other owner types are not significant.

For Denmark the ownership is analysed separately for buildings using oil or gas and for buildings using district heat. Compared to the German results it is remarkable, that thirteen of eighteen coefficients are significant. The strongest negative influence is observed for district heated buildings owned by the government. In these buildings nearly 50 kWh/$m^2$ less energy for space heating is used than in buildings owned by a private person. District heated buildings owned by public housing societies, companies, co-operatives and local authorities also consume less energy for space heating. Looking at the owner types of buildings using oil or gas, only buildings owned by co-operatives use less energy for space heating (-8.8 kWh/$m^2$). All remaining significant coefficients of buildings using oil or gas show a positive influence on the energy consumption. The highest amount of energy consumption is observed for the owner type “other local authority”, which causes a raise of energy demand by nearly 63 kWh/$m^2$. Buildings owned by the government ,with oil or gas heating, use 48 kWh/$m^2$ more energy for space heating than the reference type. On the contrary in district heated buildings owned by the government 50 kWh/m2 are consumed less than in the reference case. Yet these differences should not be overinterpreted, since only few buildings in the Danish sample are owned by other local authorities, regional authorities or the government.

**Table 4-7:** Influence of ownership status

| *in kWh/$m^2$* | **NL** | **D (SFB)** | **D (MFB)** | **F** |
|---|---|---|---|---|
| Dwelling rented | (reference) | (reference) | (reference) | (reference) |
| Dwelling owner-occupied | +7.4* | +6.9* | -6.0* | +3.8* |

**Table 4-8:** Influence of owner types

| *in kWh/m²* | D | DK (oil/gas) | DK (district heat) |
|---|---|---|---|
| private person | (reference) | (reference) | (reference) |
| dwelling company | 8.2* | -1.5 [a] | -19.7* [a] |
| company | 7.9 | 0.9 | -26.8* |
| society, fund | 28.3 | 3.1 | -19.1* |
| co-operative | -0.7 | -8.8* | -32.1* |
| local authority | 3.1 | 15.8*/62.9* [b] | -19.7* |
| regional authority | 6.0 | 10.2* | 0.8 |
| government | | 48.4* | -49.9* |
| other | 0.4 | -1.9 | -31.1* |
| not categorised | | -1.6 | -37.0* |

[a] buildings owned by public housing societies
[b] the second number refers to buildings owned by so-called, other local authorities

### 4.2.7 Occupant characteristics

Besides the building characteristics the characteristics of the occupants are expected to influence the energy use for space heating. The following characteristics have been analysed: income, age class for a reference person, number of persons in the household and Employment. Table 4-9 shows the results from the French, Dutch and German investigations. In most cases energy use raises with income, only the German coefficient for multi-family buildings indicates a decrease of energy use by an increase of the income. However here only one household per building has been observed, so the result should not be overinterpreted.

The second analysed household characteristic, the age of reference person, is expected to have a positive influence on the energy use. The estimated coefficients confirmed the expectations. Elderly people use more energy for space heating. This observation can be explained by a higher temperature level in dwellings occupied by elder people. The energy use differs by around 4 kWh/m² in Germany depending on the age of reference person. The estimated coefficients in the French analysis point at a difference of 18 kWh/m² between people younger than 30 and older than 65 years. The Dutch coefficient shows the increase of energy use per year of the reference person. For an age difference of 40 years the energy use for space heating increases by 31 kWh/m².

The number of persons in the household is another item analysed in the investigations. Here no clear pattern is found. In the Netherlands a significant decrease is observed, whereas in France first an increase, followed by a decrease is observed. Perhaps the most obvious explanation is that the shift from one to two persons in a household increases presence at home and home energy use whereas with the addition of further persons (mostly children) presence at home does not change drastically but due to less income per capita heating temperature is more controlled.

The influence of employment has only been analysed in The Netherlands and Germany. The coefficients are significant, but they show different results. The Dutch coefficient indicates a reduction of the energy use for space heating when all members of the household are employed. On the contrary in Germany energy use increases when all members are employed. This has no obvious explanation, whereas the Dutch case may be explained by a lower average indoor temperature during absence.

**Table 4-9:** Influence of occupant characteristics

| | **Coefficient (*in kWh/m² per unit*)** | | | |
|---|---|---|---|---|
| **Country** | **Income**<br>[€/month] | **Age of reference person** | **Number of persons in the household** | **All members employed** |
| **NL** | 0.0123* [a] | 0.8* | -4.4* | -14.4* |
| **D (SFB)** | 0.0032* [a] | 0 (20-34, reference)<br>-1.8 (35-49)<br>6.8 (50-64)<br>11.8* (>65) | -0.4 | 1.2 |
| **D (MFB)** | -0.0033* [a] | 0 (20-34, reference)<br>1. 3 (35-49)<br>0.4 (50-64)<br>4.3 (>65) | 2.2 | 6.4* |
| **F** | 0.0033* [a] | -18* (<30)<br>-15* (30-65)<br>0 (>65, reference) | 0 (1 pers., reference)<br>6* (2 persons)<br>-2* (>= 3 persons) | - |
| [a] transformed coefficient | | | | |

### 4.2.8 Price effects

Price effects have been analysed in all participating countries. The estimated regression coefficients are shown in Table 4-10. In order to compare the international results it is necessary to transform the estimated coefficients to coefficients which have the same unit: "€-Cent/kWh". Additionally the results of a semi-logarithmic specification are shown. Throughout only the impact of the price of the energy carrier used for heating has been considered, since prices of other energy carriers are, if at all, only relevant when heating system changes are envisaged. The influence of the price of oil has been analysed in Germany, Denmark and Sweden. Except the Swedish coefficient all results are significant and show a negative influence on the energy demand for space heating. The Danish and German coefficients are rather similar. The own price of district heat is also a item in the analyses of the previously mentioned three countries, but none of the three coefficients is significant. The influence of the price of gas has been analysed in all countries. Most results are significant but completely different, showing different signs. Surprisingly the German coefficient shows a positive influence. Possibly the used, regionally differentiated data do not show sufficient variation. The influence of the price of electricity has been analysed in Sweden. The coefficient shows a negative albeit insignificant influence.

In the French analysis one price coefficient was included which turned out to be significantly negative. This coefficient includes the energy carriers gas, oil and electricity.

In the Dutch analysis a significant positive influence of the gas price on the energy demand for space heating was observed. This result was due to inexplicably high energy demand in one particular year. Omitting this year leads to an insignificant, although still positive coefficient. Furthermore, a significant negative relationship between energy demand and the *trend* in energy prices was established: energy demand was higher in years with decreasing energy prices than in years with increasing energy prices.

**Table 4-10:** Influence of prices

| *in kWh/m² per Euro-Cent/kWh* | **D** | **F** | **S (MFB)** | **DK** | **NL** |
|---|---|---|---|---|---|
| price of oil | -8.81* | -3.27* | -2.29 | -10.63* | |
| price of gas | 5.25* | | | -14.04* | 29.91 |
| price of district heat | 3.49 | | 0.96 | 0.68 | |
| price of electricity | | | -9.11 | | |
| | | | | | |
| *in semi-logarithmic specification* | **D** | **F** | **S (MFB)** | **DK** | **NL** |
| price of oil | -0.4220* | | -0.0037* | -0-0043* | |
| price of gas | 0.1690* | | | -0.0038* | 0.1581* |
| price of district heat | 0.2343* | | -0.0018* | 0.0001 | |
| price of electricity | | | -0.0054 | | |

It should be noted that the impact of price- (and hence tax-) variations on energy consumption remains rather limited at given building characteristics. At a current price level of 0.025 €/kWh a 10% increase of energy prices leads to a maximum decrease of 3,5 kWh/m² (in the case of gas heated Danish buildings).

### 4.2.9 Subsidies and other instruments

The influence of the number of available subsidies has been analysed for Germany since data on available subsidies in 1992 per region could be obtained. These subsidies are taken as proxies for the subsidies available in previous years and that led to energy efficiency investments in the past. The coefficient shows a significant decrease of energy use in the case of single-family-buildings (-5.0 kWh/m²) by a raising number of subsidies. This limited negative impact is in conformity with expectations. For muli-family houses however no significant relationship could be established.

The impact of the national voluntary schemes has been investigated in the Danish case. The results show a negative influence (-2.8 kWh/m²) when the building has undergone a heat audit. A further negative significant coefficient (-7.9 kWh/m²) is observed for energy-tested buildings.

Certainly there are a lot of subsidies and programs which are not mentioned here. Many of these programs are included in variables like the vintage classes of buildings which show the influence of decrees and building codes or the vintage classes of boiler.

### 4.2.10 Time trend

The time trend is a somewhat messy variable that captures the impact of all kind of changes over time that have not been explicitly accounted for. In particular this includes non observed retrofit (both of the building shell and of the heating system) and behavioural changes.

A time trend has been included in almost all regressions. The results are shown in Table 4-11. Since there is no particular evidence for monotone behavioural shift over time an interpretation of observed time trends in term of efficiency gains through retrofit is attempted in the following.

In the Dutch case, the time trend should mainly capture heating system efficiency improvements since insulation measures have been explicitly modelled (cf. section4.2.4). However, a positive coefficient is observed. As in the case of the gas price, this may be due to the erratic energy use figures for 1992. Omitting this year led to an insignificant, although still positive coefficient.

In the case of district and electric heating in Denmark and Sweden the time trend conversely should reflect mainly improvements of the building shell, since no major efficiency gains may be expected for these energy carriers. Indeed the time trend for new buildings with district heat in Denmark is insignificant given that few renovations are carried out on new buildings. On the contrary for old buildings a significant negative time trend is observed. The same holds for Swedish multi-family buildings with district heating.

**Table 4-11:** Influence of time trend

<table>
<tr><th>in kWh/m²</th><th>DK</th><th>S (MFB)</th><th>S (SFB)</th><th>F</th><th>NL</th></tr>
<tr><td>oil, new building</td><td>-2.5*</td><td rowspan="2">-2.3*</td><td rowspan="9">-1.1*</td><td rowspan="9">1.6*</td><td></td></tr>
<tr><td>oil, old building</td><td>-2.8*</td><td></td></tr>
<tr><td>gas, new building</td><td>-1.8*</td><td></td><td rowspan="2">3.5*</td></tr>
<tr><td>gas, old building</td><td>-2.2*</td><td></td></tr>
<tr><td>District heat, new building</td><td>-0.1</td><td rowspan="2">-1.3*</td><td></td></tr>
<tr><td>District heat, old building</td><td>-0.8*</td><td></td></tr>
<tr><td>electricity</td><td></td><td>0.7</td><td></td></tr>
<tr><td>block-central</td><td></td><td>-1.6*</td><td></td></tr>
<tr><td>other</td><td></td><td>0.1</td><td></td></tr>
</table>

In this line of interpretation the difference in time trends between oil and gas heated buildings on the one side and buildings with district heating on the other side should be attributed to boiler efficiency gains. These correspond then in Denmark to decreases between 15 $kWh/m^2$ and 40 $kWh/m^2$ over 15 years depending on the case considered - a finding that is similar to the results obtained previously.

The efficiency gains attributable to building retrofit accumulate over 25 years to a range from 20 $kWh/m^2$ to 32 $kWh/m^2$ . If all significant retrofit measures are executed one obtains in the German case according to Table 4-5 a reduction of energy use by 23 $kWh/m^2$ and in the Dutch case by 39 $kWh/m^2$. So again the results seem to be consistent across the countries.

## 4.3 Estimation results for energy efficient investment

The influence of dwelling and household features on energy efficient investment has been analysed in The Netherlands. Table 4-12 presents the Dutch main results of the logit analysis for retrofitted glass and roof insulation, respectively. The base case is an attached single family house, vintage 1960-1969, occupied by a household of which not all members are employed.

**Table 4-12:** Logistic regression coefficients for the retrofit investment equations

| **Variable** | **Coefficient β (glass insulation)** | **Coefficient β (wall insulation)** |
|---|---|---|
| Single family house, detached | 0.185 | 0.318* |
| Apartment | -0.627* | -0.825* |
| Other type of dwelling | -0.484* | 0.0235 |
| Vintage before 1906 | -1.08* | 0.0299 |
| Vintage 1906-1930 | -1.02* | -0.144 |
| Vintage 1931-1944 | -0.816* | -0.487* |
| Vintage 1945-1959 | -0.368 | -0.553* |
| Vintage 1970-1974 | 0.0405 | 0.496* |
| Dwelling space in $m^2$ | 0.00873* | 0.00915* |
| Number of persons in household | 0.115* | 0.0257 |
| Net income (in 1000 NLG) | 0.00509* | 0.000926 |
| Age of reference person (years) | 0.0130* | -0.00994* |
| All members of household employed | 0.159 | 0.0656 |
| **Constant** | -0.321 | -1.36* |

Note: * means: coefficient significant at the 1% level.

The probability P that a particular dwelling has either type of insulation is given by the formula:

$$P = \frac{\exp(\beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + C)}{1 + \exp(\beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + C)} \tag{4-1}$$

in which $x_1 \dots x_n$ are the explaining variables and C is the constant. It can be calculated that for a "standard" dwelling (all dummy variables have a zero value), with sample mean values for the non-dummy variables (dwelling space 92.63 $m^2$, number of persons in household 2.85, net income NLG 52,930, age 45.69 years), the probability of having glass insulation is 84% and the probability of having wall insulation 30%. If the same household is, for example, living in an apartment instead of in an attached single family dwelling, then these probabilities are 74% and 16%, respectively.

Several parameters show significance (indicating for instance that retrofit occurs more frequently in newer and larger dwellings and less frequently in apartments, and that older people tend to invest more in glass insulation and less in wall insulation). Nevertheless, the results of the logit analysis are not very reassuring: the predictive power of the model is quite meagre. This is shown by Table 4-13 and Table 4-14, in which the number of correctly and incorrectly predicted cases is given for both types of retrofit investment[16].

[16] "Predicted yes" means that the model predicts a probability of more than 50% that the insulation is present.

**Table 4-13:** Predicted and observed glass insulation

| | | predicted | |
|---|---|---|---|
| | | no/n.a./unknown | yes |
| **observed** | no/n.a./unknown | 59 | 787 |
| | yes | 51 | 2756 |

**Table 4-14:** Predicted and observed wall insulation

| | | predicted | |
|---|---|---|---|
| | | no/n.a./unknown | yes |
| **observed** | no/n.a./unknown | 2441 | 84 |
| | yes | 1058 | 70 |

Only in about 70% of the cases is the model able to predict the status of glass and wall insulation correctly. The poor performance of the investment model may partly be due to the fact that unobserved variables are more important factors in retrofit investment decisions. However, it is likely that poor quality of the data (especially in the case of wall insulation) also plays a role.

## 4.4 Results of the building model

This chapter presents some of the results of the building model. Not all calculated values included in the building model are shown here. The complete building model sheets are shown in the Annex of /Schaefer, Weber 1999b/.

The heating energy demand of single- and multi-family buildings has been calculated with the help of the building model for two reference buildings. The geometric size of the houses is the same for all countries. The variables of the categories “climatic data” and “U-values, $R_c$-values” differ between the countries. The number of degree days has been taken from /Eichhammer, Schlomann 1997/ (cf. Table 3-5). Figure 4-4 shows the specific heating energy demand for both building types (constructions of today).

In conformity with the results presented section 4.2 a low heating energy demand is calculated for Danish and Swedish buildings. In all cases multi-family houses use less heating energy per $m^2$ than single-family houses. This is due to the more advantageous surface-volume ratio (or surface-dwelling ratio) for larger buildings. It is important to note that the influence of the energy efficiency of the heating systems is not included in Figure 4-4 which shows the specific heating energy demand and not the final energy consumption. Differences compared to the results of the regression analysis shown in section 4.2 may be due to the building geometry, the climate and incomplete application of standards. These issues will be discussed in some more detail in section 4.5.

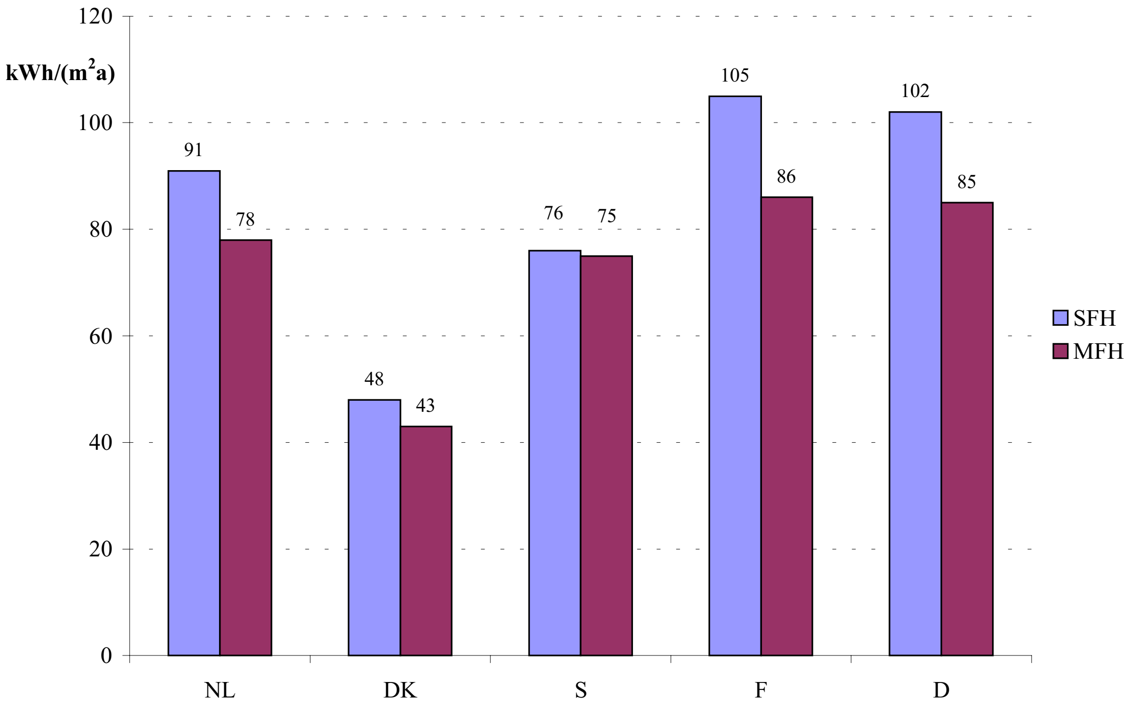


**Figure 4-4:** Specific heating energy demand for single- and multi-family buildings

To eliminate the impact of climatic differences between five countries another calculation has been made using the same climatic data for each country – the climatic data of Germany. Figure 4-5 shows the heating energy demand for single- and multi-family houses built according to the different national standards but put in the German climate.

With the same climatic data, the same behaviour of the occupants and the same building geometry the heating energy demand depends on the remaining variables of the category "U-values, $R_c$-values" (cf. section 0.2). The results shown in Figure 4-5 are hence a measure for the insulation standards of the buildings in the participating countries. According to these results the Danish and Swedish standards impose rather similar requirements on heating energy efficiency. Also the Dutch and German values for single-family houses are higher than the Danish and Swedish. The highest energy demand is observed for the French single-family building. This does not mean that French standards should be the same as the Swedish. Given the milder climate in France, Swedish standards would probably be economically not efficient (cf. section 0.2).

Another influence that may be analysed by means of the building model is the influence of the vintage classes of buildings. The building model can be used to simulate the energy demand of different vintage classes (including standards) when data concerning U-values and $R_c$-values is available for buildings of different vintage classes. For German houses the U- and $R_c$-values of different vintage classes are available from /Ebel et al. 1992/.

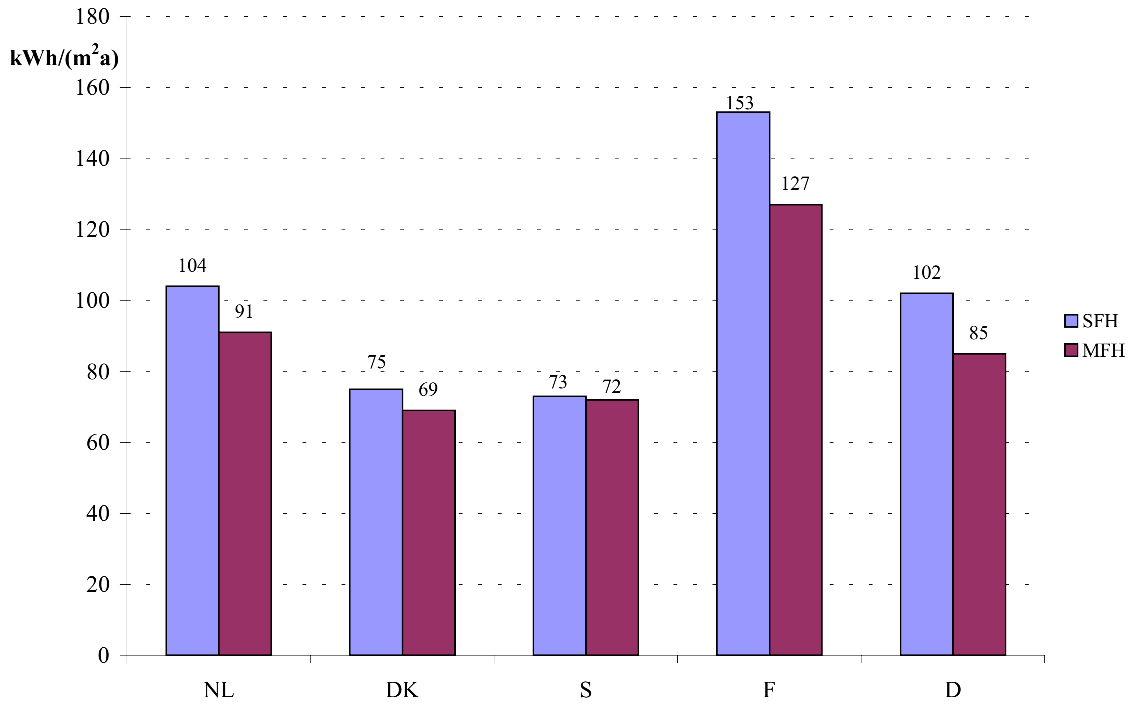


**Figure 4-5:** Specific heating energy demand of single- and multi-family houses (German climate)

However one has to bear in mind that not only the insulation differs between vintage classes but also the geometry of the building (e.g. number and size of windows). Therefore two simulation series have been carried out: Differences in the heating energy demand are only due to changes by the U- and $R_c$-values. The influence of the design is included in the category "actual geometry". Figure 4-6 shows the specific heating energy demand of multi-family houses. The U- and $R_c$-values are taken from existing German buildings built in the different vintage classes /Ebel et al. 1992/. But the not actual values have been taken, since in one vintage class the reference building of /Ebel et al. 1992/ is a strongly retrofitted building which is not typical for this class. Therefore weighted U-values from the buildings as originally built and as renovated in a trend scenario have been used to calculate the specific energy consumption. The results are shown in Figure 4-6. For the actual geometry a moderate increase is observed until the 1960s followed by a decrease. Under the assumption of constant geometry the heating energy demand increases considerably from the 1920s to the end of the 1960s, afterwards a decrease similar to the previous cases occurs. Hence until the end of the 1960s changes in the building design have partly offset the effects of better U- and $R_c$-values, whereas afterwards changes in the building design had only limited impact.

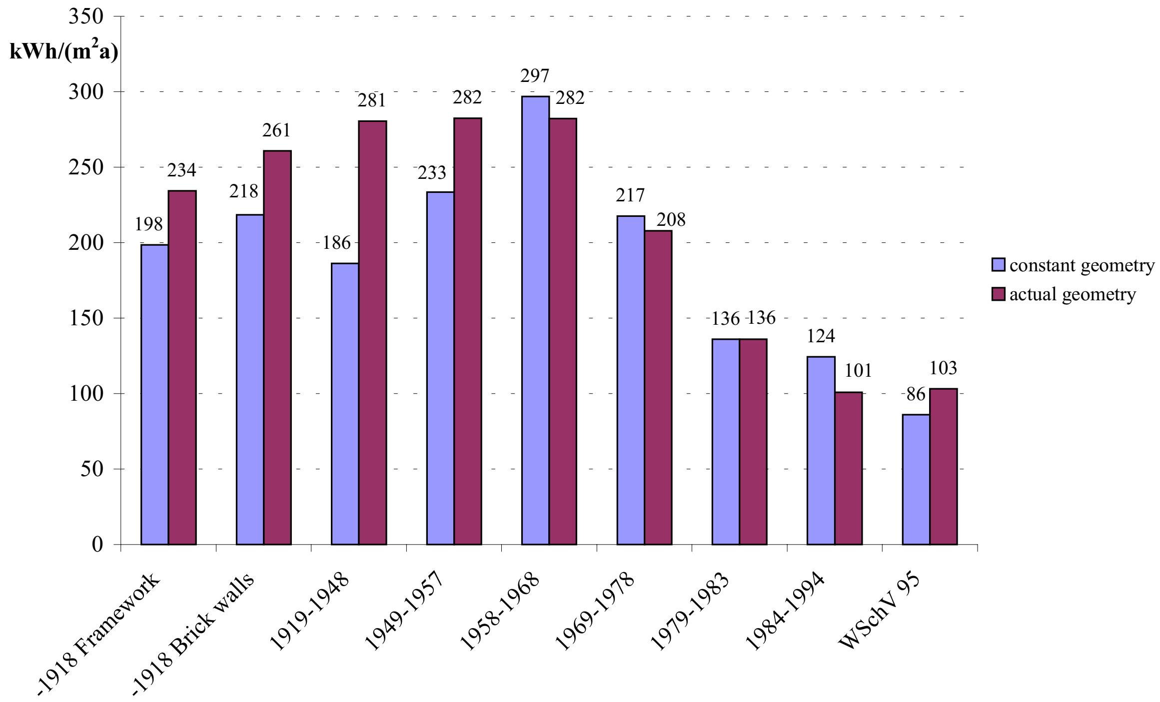


**Figure 4-6:** Specific heating energy demand of German vintage classes (MFH)

## 4.5 Comparison of building simulation results

In the previous sections, two different methods have been used to analyse the heating energy consumption for buildings. A comparison of the outcomes can offer additional insights. It has however to be undertaken and interpreted with caution given that despite a common methodological foundation (cf. chapter 0) the treatment of some phenomena differs. In particular the heterogeneity of building characteristics within one vintage class and occupants behaviour is dealt with differently in both approaches. In the building model two specific buildings are simulated, whereas in the sample analysis besides a distinction of building types and the introduction of some retrofit variables the heterogeneity is captured by the error term. Similary the occupants behaviour is assumed to correspond to some "average" in the building model, while in the sample analysis household characteristics like age and income capture some of the variation, the rest being again included in the error term. For a comparison the estimated parameters of the statistical analysis have to be used to simulate the specific building(s) analysed by means of the building model. Figure 4-7 shows the obtained results. The building which has been analysed is a multi-family building (592 m$^2$) of the latest standard observed in the sample using oil (gas in the case of The Netherlands) (cf. Table 3-1 and Table 3-4). For the annual efficiency of the heating system including the boiler and the radiators 80% are assumed in all cases. The number of degree days has been taken from/Eichhammer, Schlomann 1997/.

According to Figure 4-7 the results of the building model and the empirical analysis are in line in the case of The Netherlands. In the case of Denmark, France and Germany the empirical results are higher than the calculated ones. This points at an incomplete application of the standards in these countries.

Explanation for the differences might be national differences in the annual efficiency of the heating system, in the building geometry or in the occupants behaviour. But the observed differences in the case of Denmark, France and Germany are too large to be fully attributed to such reasons. For Sweden the lower observed values could be due to an over fulfilment of standards, which is included both by economic incentives – in cold climate good insulation saves more money – and by a certain “culture and practice of energy conservation”.

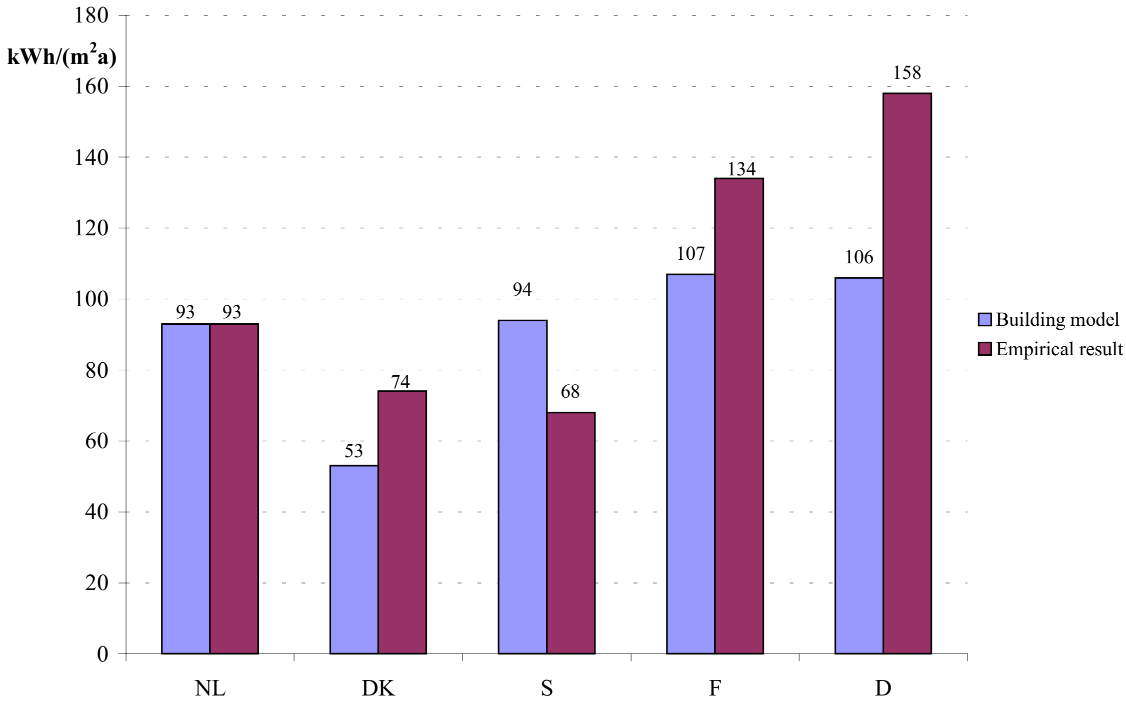


**Figure 4-7:** Comparison of empirical results and calculated results (MFH), final energy consumption

# 5 Assessment of policy instruments

Based on the inventory of policy instruments (cf. chapter 0) and on the results of the empirical analysis (cf. chapter 0) this section develops an assessment of policy instruments for energy conservation in residential space heating in the five participating European countries and beyond. Also the obtained results are put in perspective by comparing them with theoretical arguments and the findings from other studies.

For assessing policy instruments two main criteria may be considered: *effectiveness* and *efficiency.*

*Effectiveness* describes to what extent a given objective has been reached by means of the policy instruments. Assessing the *effectiveness* of policy instruments raises some methodological complications. First of all, the objective of the policy maker should be well defined. Otherwise it is impossible to determine whether and to what extent the policy objective has been achieved. Secondly, one should have convincing evidence on the causal relationship between the use of the policy instrument and the goal achievement. The successful realisation of a policy objective may well be due to other factors than the policy instrument. On the other hand, one instrument may have an impact on several policy objectives simultaneously. Finally, one should be aware of the fact that a policy instrument may be effective in particular circumstances only and ineffective if these circumstances do not occur.

In addition to effectiveness, *efficiency* is generally considered to be an important criterion to judge policy instruments. Efficiency can be defined as the extent to which maximum effectiveness has been reached with a given budget, or a given impact has been realised at the lowest possible costs. From an economic (welfare) point of view, the costs to be considered should include all (monetary and non-monetary) costs to society; not only the public budget expenditures.

Before the empirical evidence of our own and other research is discussed, in section 5.1 theoretical considerations on effectiveness and efficiency of different policy instruments are presented. Then in section 5.2 standards are reviewed, in section 5.3 taxes are discussed and in section 5.4 subsidies. Finally in section 5.4.4 other instruments are analysed.

## 5.1 Theoretical considerations

Besides the empirical analysis of effects on heating energy consumption also a theoretical assessment of policy instruments is needed – on the one hand to guide the empirical investigations (cf. chapter 0) but also to complement the empirical analysis where it must remain incomplete due to limited data availability. In the following some important elements for a refined theoretical assessment and a comparison of policy instruments for energy efficiency in residential space heating are sketched.

First basic economic insights are recalled (section 5.1.1) and then extensions of this theory and their implications for policy instruments are discussed. Section 5.1.2 deals with informational problems neglected in standard theory, section 5.1.3 handles dynamic aspects such as discounting and technology progress. Section 5.1.4 is on institutional and distributional problems.

### 5.1.1 Economic theory – efficiency of taxes and permits

In environmental economics environmental quality is treated as a good with demand and supply curves (e.g. /Baumol, Oates 1988/). Since it has to be considered as a public good, no market price exists and supply would be too low without government intervention. But if the government sets a tax *t* equal to the equilibrium price *p** (the so-called Pigovian tax), an optimal supply of environmental quality is ensured and an optimal welfare level attained (cf. Figure 5-1). Another alternative is to create tradable permits for the optimal supply quantity *q** of environmental quality. Other policy instruments like standards or subsidies can in this framework only be suboptimal since they don't take into account differences in marginal supply cost (standards) or they distort market prices (subsidies).

However this model is rather simplistic and careful investigation is required whether it is applicable if real world complications are taken into account.

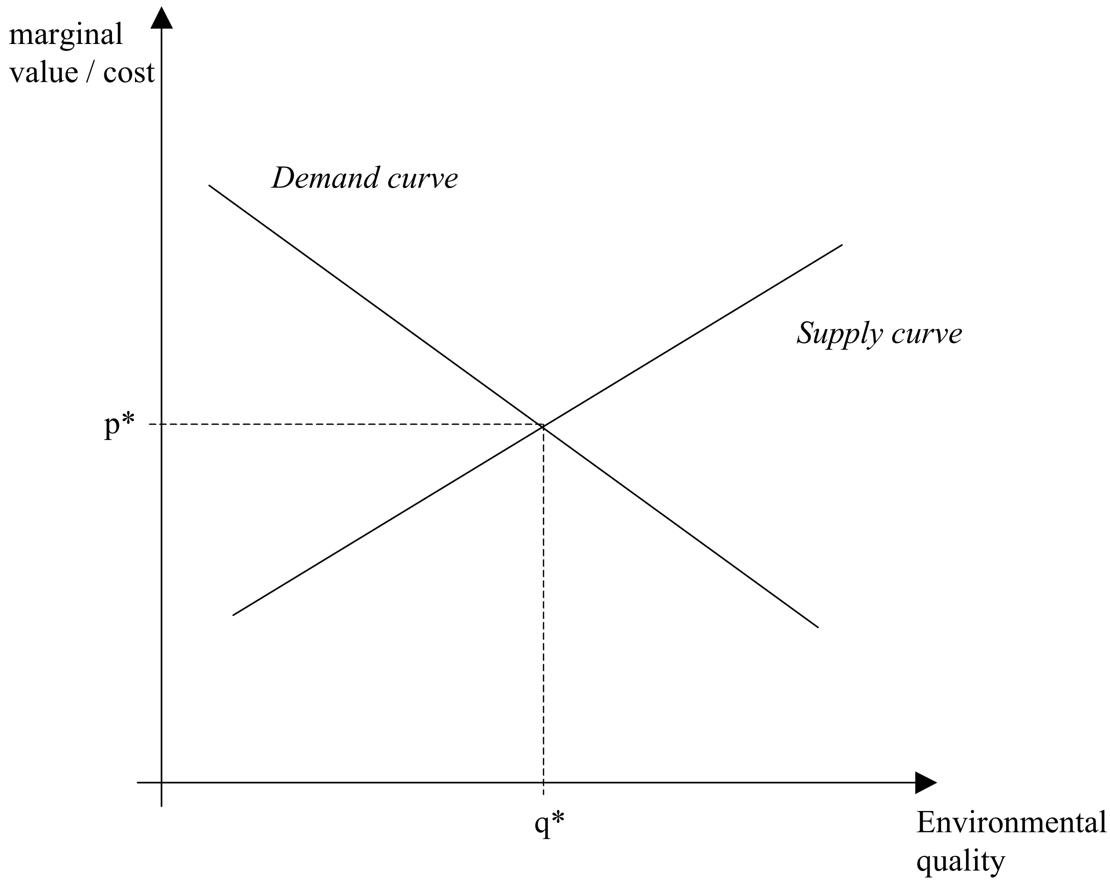


**Figure 5-1:** Demand and supply of environmental quality – simple model

### 5.1.2 Informational problems and bounded rationality

A first type of real world complications is the absence of complete information. This holds for single agents as well as for the society as a whole. Related to the problem of incomplete information of agents is the observation that agents do not always act rationally in an economic sense.

#### 5.1.2.1 Incomplete information of agents

Several kinds of incomplete information can stand in the way of investments in the heating energy efficiency. Table 5-1 presents a number of possible areas where information may be lacking (or incorrect information may be existing), as well as possible remedies for that type of information deficit.

**Table 5-1:** Types of information deficit and possible remedies

| Information deficit | Remedy |
|---|---|
| Insufficient information on heating energy consumption | - more frequent and better feedback, e.g. through better visibility of the meter<br>- energy use monitoring actions<br>- audits |
| a lack of awareness of the consequences of daily behavior for heating energy consumption | information provision on issues like ventilation, use of thermostats etc. |
| Incorrect information on energy saving technology, based on rumors and prejudices | - information provision by trusted sources<br>- example setting |
| a lack of information on the actual implementation of the technical measures taken (information asymmetry: the client does not always know whether he really gets what the supplier promised) | independent monitoring, quality checks, certification etc. |
| Uncertainty on future development of technology | exploration of long term technology development |
| Uncertainty on future development of energy prices | design an energy tax/charge with predictable rates for several years ahead; possibly adapt rates to market prices so as to mitigate large fluctuations in end user prices |

Incomplete information is often considered to be a problem particularly relevant for private consumers. It can be included in the previously sketched model by assuming transaction costs (notably for information gathering) that lower the effective demand curve from $D_0$ to $D_1$ (cf. Figure 5-2). At a given price level then less environmental quality $q^u$ is demanded and the optimal price is lower then previously, leading however also to welfare losses. In this case information measures such as information leaflets, audit schemes or the energy test carried out in Denmark can contribute to increase total welfare, provided their cost is below the reduction in transaction costs they are able to achieve.

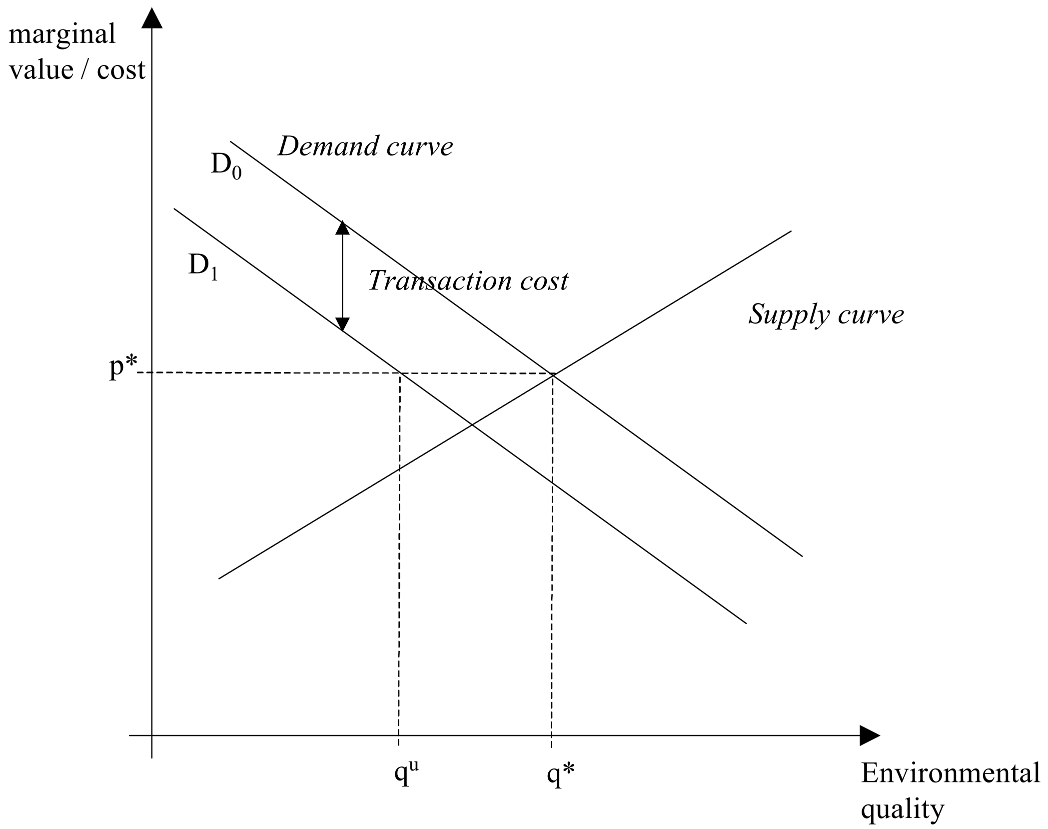


**Figure 5-2:** Demand and supply of environmental quality – model including transaction costs

Also standards (and subsidies) can have the effect of lowering transaction costs by providing the consumer with part of the information (the requirement level) he needs for decision making. Instead of exploring the supply curve as a whole he has then only to look for the pre-specified level. However this argument should not be pushed to far, because it leads to the abandon of the idea of consumer sovereignty.

#### 5.1.2.2 "Bounded rationality"

Human behavior is not always "rational". That is, even if they would have complete information, people should not always be expected to maximise their "utility" in the sense of looking for the optimal trade-off between comfort level, heating energy costs and costs for energy saving equipment[17]. Here we are entering the area of psychology. An important cause is the fact that most human decisions are habitual decisions.

A possible remedy then clearly is to bring energy use for space heating into the much smaller area of non-habitual decisions. This will not be easy, because there are a lot of other issues competing for this small area. Strong marketing efforts will be needed. It is preferable to use a wide variety of instruments and channels at the same time, so that the issue is raised

[17] If we take a broader definition of "utility", which includes the convenience of sticking to habits, then of course it may be perfectly rational to spend more money on heating than necessary.

to the upper parts of the consciousness of the public at large. Subsidies can play a role here, not so much by turning the net cost of energy saving investments into net benefits, but rather by being just another sign that attracts people's attention to the issue.

To a certain extent, however, one has to accept the fact that decisions regarding heating behaviour have a routine character. This means that technologies should be stimulated which can reduce energy use without requiring continuous attention from the user, for example "intelligent" thermostats.

#### 5.1.2.3 Uncertainty and the precautionary principle

Besides lack of knowledge (and rationality) at the level of single individuals there exists also in environmental questions often quite some uncertainty at the societal level. One example is the uncertainty on the exact impacts of Climate Change which make then any estimates of demand curves for environmental quality (in terms of emissions) rather difficult. As /Schöb 1996/ argues, depending on the prevailing type of uncertainty and the elasticity of demand and supply curves, then either emission certificates or taxes may be more appropriate.

But additionally in the case of decisions under uncertainty risk aversion may occur. Every-day observation, especially of the growing insurance market, suggests that risk aversion is an important aspect for an appropriate descriptive analysis of decision making and economic theory has successfully exploited the concept in the last decades under normative premises. In the case of the demand for environmental quality risk aversion will lead to a preference for robust instruments which are able to deliver sure effects even if they are more costly compared to instruments with more uncertain effects. This argument also plays in favour of standards, where the effects are more predictable compared to taxes. If however uncertainty on long term energy prices is the dominant barrier for investments in energy conservation, then taxes/charges may be preferable (possibly at a flexible rate so as to compensate for energy price fluctuations and keep the end user price at a stable/predictible level).

Another point that has been made in the Climate Change discussion, notably by Nordhaus, is that under uncertainty it may be appropriate to postpone costly decisions until the uncertainty is (at least partly) resolved. This at first sight contradicts the previous considerations. However the contradiction can be explained as a consequence of differences in risk perception and degree of risk aversion. Enacting now robust instruments is preferable if the perceived risk is high (think of irreversible climate changes with catastrophic consequences that can not be hedged by financial instruments) and the degree of risk aversion is also high. Otherwise the opposite is true. This holds then however for any type of policy instruments with high economic cost – if one accounts for possible "lost opportunities" (cf. section 3.4.2 and section 5.1.3) it might even be an argument in favour of standards.

### 5.1.3 Dynamic aspects

The question of efficiency of policy instruments has been so far treated basically as a static one. However the temporal dimension has been touched upon in the previous section on uncertainty. But also the question arises, how benefits and costs occurring at different points in time should be weighed. This is discussed together with the implications for policy intervention on energy efficiency in the following. An important dynamic aspect is also the question of “lost opportunities” already touched upon in section 3.4.2. Also the “rebound” effect, the increased consumption after the installation of a technology with improved efficiency, can be considered as a dynamic phenomenon and will therefore be discussed below. Finally also the effect of the policy instruments on the development of energy efficient technologies over time, i. e. technological progress, has to be considered.

#### 5.1.3.1 Choice of appropriate discounting

The discussion about appropriate discounting rates has been long-lasting in cost-benefit-analysis and environmental economics. Neo-classical theory makes the point that in market equilibrium market interest rate, marginal capital productivity, social discount rate and individual time preference should be identical. However this argument relays on the assumption that “complete markets” exist – an assumption as heroic as the one of the fully informed consumer – and that today’s decision makers adequately account for preferences of future generations – either because they are assumed to live forever or because they maximise the intertemporal wealth of themselves and their descendants. Since neither is the case a social discount rate, appropriate for the basic sustainability principle of “making future generations not worse of”, should be lower than the individual time preferences that determine market interest rates.

An additional argument in favour of a low long-term discount rate has been made by /Weitzman 1998/. He argues that in the long run the discount rate itself may be subject to uncertainty due to uncertainty about technological progress and future preferences. Then formally it can be shown that even in the absence of risk aversion the appropriate discount rate to be chosen for the long term is the lowest possible one. Weitzman in his formal treatment does not quantify this lower bound, he only indicates that it is greater or equal to zero.

The implication for policy instruments is again that future benefits (and costs) should be taken more into account than under conventional economic reasoning. Per se however no particular instrument is favoured in the view of this argument.

#### 5.1.3.2 “Lost opportunities”

Buildings have a long lifespan and usually during their lifespan are retrofitted several times to a varying extent. E.g. in Germany for the outdoor plaster a renovation cycle of forty years is assumed whereas heating systems are replaced on average every 15 to 20 years. At these renovation moments additional investments can be done with relatively low costs to increase the energy efficiency of the building. Conversely if these moments are not captured then the investment costs to implement energy efficiency measures are considerably higher[18]. This is certainly an argument in favour of mandatory standards if other market imperfections, namely incomplete information, are present. With limited additional costs in the construction phase considerable improvements of the environment can be reached, whereas the incentive from a tax would be anyway limited to those currently in an investment situation.

However standards on the building shell are so far almost exclusively applied to new buildings and only some discussion has occurred in the Netherlands and Germany how standards could be made mandatory for retrofit. Here subsidies may decrease the number of “lost opportunities”, if the effect of taxes is considered to be too limited. Particularly in a situation with risk aversion and liquidity constraints overall welfare could be increased through subsidies despite the price distortion and deadweight losses they introduce.

#### 5.1.3.3 Rebound effect

Energy efficiency improvements reduce the marginal cost of producing an additional unit of energy service (e.g. heated room). They have therefore similar effects on energy service consumption as a price reduction for energy. Under the assumption of utility-maximising consumer behaviour it can even be shown that the rebound elasticity for a (cost-free) efficiency improvement is equal to the short term price elasticity (at constant equipment) with opposite sign (cf. /Weber 1999/).

#### 5.1.3.4 Incentives for technological progress

In a dynamic context also the impact of the policy instruments on technological progress has to be looked at. Here the case seems rather clear cut: standards only provide an incentive to reach a given requirement level at minimum effort, but no incentives (except market energy price) are provided to exceed the requirement level. The same holds for subsidies given for a certain technology level. On the contrary taxes increase the marginal cost for each unit of pollution and therefore provide a continuous impulse towards more efficient technologies. One might imagine schemes of regularly tightened standards that are sufficiently announced

[18] To capture these facts in a formal model, a dynamic model formulation (as opposed to the static one used previously) has to be chosen, and then path-dependency of decisions has to be modelled.

in advance to provide a similar impulse towards more efficiency, but this raises the question who sets the standards, touched upon again in section 5.1.4.

### 5.1.4 Institutional and distributional aspects

Besides neglecting incomplete information and dynamic aspects the basic model sketched in section 5.1.1 suffers also of the flaw of accounting only in a very simplistic way of the agents interfering on the problem. One point is that the consumers as the ultimate sovereign do not provide themselves environmental quality (or energy efficiency) but employ/pay others to do so. This may raise so-called principal-agent problems. Another point that is neglected often in theoretical analyses but that is very relevant for any practical implementation is the distribution of benefits and costs over different groups of actors. Finally besides considering consumers and producers as actors also the role of politicians and administrations enacting new instruments may be analysed.

#### 5.1.4.1 Principal-agent problems

What happens if a client asks an architect to make plans for a building and craftsmen to execute these plans and these experts are selfish and opportunistic? The economic principal-agent-theory investigates in general the implications of one utility-maximising individual acting on behalf of another. Key concepts are then *hidden information* and *hidden action.* These seem to be highly applicable to the case of energy efficiency in buildings: Particularly architects have specialised information that is not available to their clients. If in addition they are (together with civil engineers) in charge of the calculation of the heating energy requirements there is danger that they will use this hidden information to their own benefit (easy planning or aesthetic benefit), and the client (as well as the regulator) will not necessarily obtain their maximum benefit in form of reduced heating cost. A similar reasoning holds for the (mostly) hidden action of the craftsmen during the construction phase that can lead to deteriorated heating performances, e.g. through heat bridges (cf. e.g./Erhorn et al. 1998/).

This type of performance problems is particularly relevant for standards and subsidies, where the building owner has far less incentives through high energy prices to put sufficient pressure on the experts than in the case of taxes. To alleviate these problems an independent auditor may be introduced. This could be the municipality who could control the calculated heating energy requirements and the construction phase. However such a control implies additional costs and may hence not lead to overall welfare gains.

Also the owner-tenant dilemma can be viewed in a principal-agent framework. A possible action of the owner (the agent in this case) to improve the energetic efficiency of his building is mostly hidden to the eyes of the tenant (the principal), since it is only indirectly and with time delay observable by the tenant through a lower energy bill. Therefore the tenant will in general not be willing to pay an increased rent to refinance the investment. Consequently few incentives for the owner exist to increase the energy efficiency of the building.

### 5.1.4.2 Liquidity constraints

Most building investments are at least partly financed from credits. Although banks more easily provide mortgage loans since they can obtain the building as a security they allot the client only limited sums. This implies that at least part of the building owner are credit restricted and that they would undertake otherwise more investments in energy efficiency. On average the implicit discount rate of all building owners is then higher than the market interest rate[19]. This leads to a decrease in the effectiveness of environmental taxes since the discounting factor of the individuals is increased. This is not or only partly the case for subsidies, whereas for standards the overall effect depends on whether the credit restricted individuals then renounce to invest at all or whether they shift part of the investment from "luxury equipment" to then mandatory energy efficiency equipment.

Such credit constraints may be explaining why some policy makers wish to give subsidies to energy efficiency technologies. Since adjustments in energy consumption appear to take place via adjustments in technology a technology subsidy may be almost as good as a carbon based fuel tax if it is designed carefully. This suggests that a technology subsidy, although it is a second best instrument to carbon based fuel taxes, can be an alternative policy measure that is almost as efficient as a fuel tax, and at the same time alleviate distributional problems. An important point, though, is that it is very difficult to design technology subsidies so that they reflect the benefits in terms of reductions in carbon dioxide emissions for various technologies.

### 5.1.4.3 Distribution of benefits and losses

Although eco-taxes corresponding to an internalisation of externalities have been put forward in theory for quite some time as an adequate instrument for increasing ecological efficiency, their introduction encounters substantial opposition in the public debate. Similarly also for new standards objections are encountered, notably in Germany in the case of the thermal insulation ordinance enacted in 1995. These objections are often related to economic losses incurred by some actors. In the German example it was in particular the brick industry who feared that their building materials would be less sold when insulation requirements are tightened. In the case of eco-taxes the opposition is broader since this instrument creates additional government funds and consequently puts higher charges on the consumers and produc-

[19] A number of empirical studies have found high internal discount rates for some consumers, cf. Dubin (1993).

ers. Even if a tax cut in other domains is promised, there will probably be loosers and thus opponents to that policy (e.g. the basic materials industry for energy-/$CO_2$ taxes). Furthermore in the line of the debate on policy failure the credibility of the tax reductions is often questioned.

The distribution of benefits and losses is not directly linked to the effectiveness or efficiency of policy instruments yet it has clear links with the practicability of the instruments. Here voluntary agreements are most highly rated by the concerned parties since they offer the possibility for negotiation and adaptations and also new subsidies will hardly be opposed. However they have often low effectiveness if there is not a credible menace of compulsory measures for the case that the "voluntary" agreement fails. The distribution of benefits and losses is most problematic in the case of taxes and also standards may encounter some difficulties.

#### 5.1.4.4 Vote maximising politicians and pressure minimising administration?

Similar to viewing building owners, architects and craftsmen as utility-maximising individuals also politicians and the administration can be viewed as such. This transgresses then the frontiers of traditional economy, where the government is mostly viewed as impartial regulator. Also the focus shifts then from normative analysis which policy instrument is best for given purposes to a descriptive purpose which instrument is likely to be adopted, given the behaviour of the relevant agents.

Political economy in this kind of - non undisputed - analyses usually assumes that politicians are maximising their votes. For administration a similar assumption could be that it tends to minimise the pressure it is submitted to or that it aims at perpetuating and extending its influence.

From vote maximisation it is usually deduced that politicians privilege instruments that yield benefits for many and only harm few and that they tend to look more at the short term than at the long term effects of instruments.

For heating energy efficiency the first argument yields no clear-cut results. It might explain part of the reluctance to introduce eco-taxes since these would touch everybody in the case of energy and $CO_2$. But there is then also no clear argument in favour of standards or subsidies because the benefiting groups are rather small in both cases, essentially the building industry in the first case, the building owners on the point to construct or renovate in the other. The second argument however gives a unequivocal hint at a political preference for standards and subsidies. The distortion of prices and markets produced by these interventions are particularly important in the long run, whereas they can yield positive and visible effects in the short run, if not on the environment, then on the perception of political action and initiative.

Administration is often treated as part of the political system in analyses of political economy. But it might be interesting to look at it as a separate entity. The assumption of pressure minimisation seems particularly applicable during the decision process for a new policy. Here it will favour instruments that are not rejected by large and important lobbies, such as (well-defined) standards, or that are even pushed by a lobby, as is the case for many subsidies. Also the goal of maintaining and extending its own influence will push an administration towards standards and subsidies that require important efforts for control and attribution by specialised staff whereas taxes that rely more on market forces are less attractive in this view – if at all they are necessitating extra staff among Tax Men.

Altogether concepts of political economy can certainly contribute to explain the observable preference in practical politics for standards and subsidies. However these should not be overemphasised, since the previous paragraphs lined out that there may also be substantial reasons to rely in practice more on standards than on taxes.

## 5.2 Standards

In the past standards have played an important role for increasing the energy efficiency of buildings. Correspondingly several assessments have been carried out (cf. section 5.2.1) and considerable effects on the heating energy consumption are observed (cf. section 5.2.2). These results are interpreted in section 5.2.3 and in section 5.2.4 recommendations for future standards are derived.

### 5.2.1 Previous assessments

A continuous reduction in average heating energy consumption of new dwellings since the mid-1970s has been observed by several studies. For instance, /Van Oosten 1998/ states that a newly built dwelling in the Netherlands now uses 80 % less gas than one which was built in the early 1970s (700 versus more than 3,000 $m^3$ gas). According to /Vreuls 1994/ a standard dwelling built in 1994 needed 73.5 % less energy for heating than a comparable dwelling built in 1973 (850 versus 3,200 $m^3$ gas). /Koevoet 1999/ states that dwellings built presently use one third of the heating energy which dwellings built more than 25 years ago require. Thus, estimates of the theoretical efficiency gains achieved in the last 25 years range between 67 and 80 %.

In Germany a study by /Ebel et al. 1995/ demonstrates on the basis of 40 executed renovation and building projects that substantial energy savings are not only possible in theory but may be obtained in reality. However, a follow-up of a larger urban development project by /Erhorn et al. 1998/ has shown that in practice the realisation of low-energy-buildings encounters several obstacles both in the planning and execution phases. If no continuous follow-up occurs the obtained energy efficiency is likely to be lower than planned.

The Danish as well as most other governments believes that there is still considerable room for improvement of newly constructed buildings but also for maintenance and/urban renewal of existing buildings, cf. The /Danish Energy Agency 1995/. Hence the building standards have recently been tightened further in Denmark, 25% in terms of average heat loss of building components, in the period 1995 to 1998. It is the aim to reduce energy consumption in new buildings by additionally 33 % in 2005. Also the German "Energieeinsparverordnung" which has presented as a draft version in June 1999 (cf. /IWU 1999/) and which may become effective in 2001 has the goal to reduce the energy consumption by about 30 %. In the Netherlands the Energy Performance Standard introduced in 1995 is to be tightened in 2000.

The building regulations described before mostly affect new houses. Regulations pointing at the existing housing stock, i.e. especially houses built before the 1970s, do not exist at this point. Such regulations are currently under discussion in the Netherlands and Germany.

### 5.2.2 Empirically observable effects

The results of our empirical analysis show a strong influence of the staged introduction of energy efficiency standards for new dwellings since the 1970ties. Evidence suggests that building regulations have a significant effect on energy consumption for space heating. Significant reductions in the consumption of space heating can be observed for houses built in 1975 or later when compared to older houses.

Figure 5-3 illustrates this by showing the development in Dutch standards ($R_c$ values for wall insulation, as reported in /Oosterhuis, Nieuwlaar 1998a/) and the decrease in heating energy use by vintage, as estimated by the coefficients in the linear specification of our regression analysis.

Households living in dwellings built after 1989 consume some 50% less heating energy than similar households in similar dwellings built in the 1960s and early 1970s. This is a remarkable achievement, but the observed energy savings are significantly lower than the theoretically achievable figures presented in section 5.2.1. This holds also for other countries (cf. /Schaefer, Weber 1999b/). One reason could be that the prescribed standards are not fully implemented. Furthermore, there may be to some extent a "rebound" effect: people living in dwellings with improved insulation tend to behave differently. They may be less concerned about energy saving, or they may enjoy a higher level of comfort (higher room temperature, larger heated area) than people living in older, less energy efficient homes. Given the low price elasticity observed (cf. Section 5.3.2), this effect should however be of minor importance.

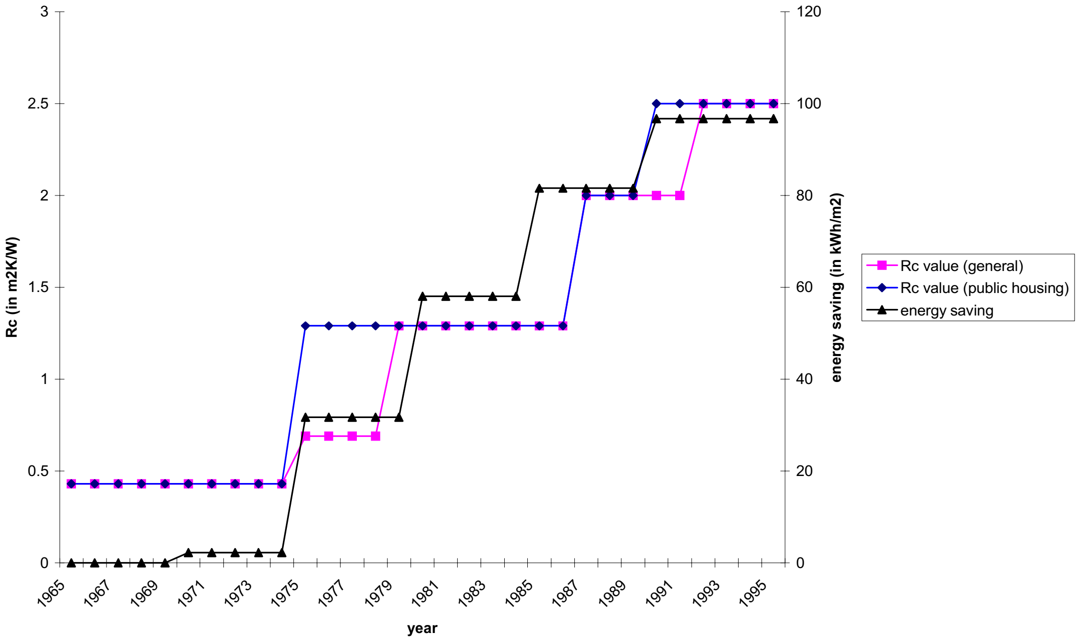


**Figure 5-3:** Development of insulation standards (walls) and energy conservation in the Netherlands, 1965-1995

Besides standards on building insulation and/or overall energy efficiency also norms on particular building equipment have been issued. E.g. German boilers must be equipped with sensors for outside temperature to adapt the mains temperature to the heating energy requirements (/BMWi 1998/). Also all dwellings have to be equipped with thermostat valves (/BMWi 1998/). According to the empirical results for Germany, only the second measure leads to significant, although limited reductions in energy use (-7.6 kWh/m$^2$). Concerning improvements in older buildings, evidence from /Leth-Petersen,Togeby 1999/ also suggests that there may be room for improving energy efficiency. The efficiency of the boiler, which is regulated by the German ordinance (/BMWi 1998/), is according to the empirical results for German oil boilers less linked to the vintage than expected. Here some self-selection may have occurred, however the observations were made before the ordinance was enacted. Hence the ordinance is probable to have only a limited effect on heating energy consumption.

### 5.2.3 Interpretation

The phased introduction of increasingly stringent energy efficiency standards for new dwellings has in all likelihood been an *effective* instrument to reduce the residential heating energy consumption. Although one might argue that technological progress would have led to continuous improvements in the energy balance of dwellings anyway, it is hard to believe that the same speed and scope of penetration would have been achieved without any regulations. It is well known that the introduction of new technologies on the market is often a cumbersome and time consuming process. Standards making the application of the new technology obligatory can speed up this process considerably.

The *efficiency* of applying uniform standards, however, is questionable. If the overall supply of housing were sufficient *and* housing quality were only dependent on energy performance, people could choose themselves if they want to be affected by building regulations as they decide themselves whether to build a new house or not. Then building regulations affecting new houses could be efficient[20]. Yet in practice both households and buildings are heterogenous, and for example for households having already a low heating energy demand (e.g. due to their lifestyle) the (investment) costs associated with meeting the standards may be very high when expressed in terms of money per unit of energy saved.

Building codes appear to be hence an effective way to obtain substantial reductions in energy consumption in newly built houses when compared to older houses, i.e. houses built before the seventies. Regulations pointing at the insulation of the existing housing stock, i.e. especially houses built before 1977, do not exist at this point. Such standards pointing at old houses are more difficult to be made effective. In Germany already obligations to retrofit old boilers exist (/BMWi 1998/), but for the building shell currently such measures are only applicable in the case of major renovations. Here serious control problems arise.

Furthermore it is even more certain that standards for existing houses will not be an efficient way to obtain improvements in overall energy efficiency as they may imply rather serious detrimental welfare effects as people do not decide themselves if they want to be affected by the regulation, as is the case with building codes. Thereby, people are just imposed extra costs.

Meanwhile, also the frontiers of what can be realised for new buildings with construction measures, such as insulation, are becoming visible. Other options to improve the energy performance of new dwellings have to be considered, such as the use of condensing boilers, solar boilers and/or heat pumps. The new standards like the Dutch Energy Performance Standard (introduced in 1995 and to be tightened in 2000) take such options into account. This also creates more flexibility by making it possible to look for the most effective and efficient combination of measures to implement the standard, depending on local circumstances.

### 5.2.4 Recommendations

Overall, building regulations seem to be an effective way to restrict energy consumption for space heating in new dwellings, although the effectiveness is often below the one expected from engineering / technical simulation estimates. Standards for existing houses cause detri-

[20] Note that at this point no study exists that evaluates the welfare implications of building regulations.

mental distributional welfare effects. Low-income groups often live in older buildings and are hence imposed extra costs through mandatory retrofitting. Given the heterogeneity of old buildings these costs per unit of energy saved are also likely to be some cases very high. Nevertheless a further development along the following lines seems desirable:

- building shell and heating system should be treated in an integrated way,
- also the inclusion of other energy uses in the house (domestic hot water, electrical appliances) in the standard is recommendable, since these are of growing importance,
- therefore a key figure based on final energy consumption should be used,
- treatment of different final energy carriers has to be reflected carefully – one might use non renewable primary energy to create an equivalence[21],
- not more than 2 different calculation methods should be proposed (standard & simplified),
- even the proposition of a simplified calculation method based on component U-values or similar requirements is not recommendable: either it lowers considerably the energy efficiency, or it imposes unnecessary strong requirements,
- incentives for a compact architecture and an orientation of windows to the south should be included[22],
- the calculation of the heating energy requirements should be done according to EN 832,
- threshold levels have to be dependent on the heating degree days in the countries or regions considered,
- given that energy efficiency is not obtained at zero costs, threshold levels for energy consumption should increase less than the degree day figures.

## 5.3 Taxes and charges

Until recently, taxes and charges have been of minor importance for the energy efficiency of buildings in the countries under study except Denmark. In the last years however a large number of assessments has been carried out (cf. section 5.3.1) and also our own empirical analysis provides evidence on the obtained effects (cf. section 5.2.2). These results are interpreted in section 5.3.3, also in view of the theoretical considerations of section 5.1 and in section 5.2.4 recommendations for concrete future standards are derived.

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[21] This however neglects the environmental effects related to the production of devices like solar collectors. Also different methods exist for calculating primary energy related to heat from CHP and electricity from nuclear.

[22] The use of a building with similar geometry but standard equipment as a reference like in the French norm should therefore be avoided.

### 5.3.1 Previous assessments

Taxes and charges can have an impact on heating energy use by their upward influence on the consumer price. Thus, although energy taxes (aiming to have a steering impact on household energy use) were introduced in many countries only in the nineties, analyses of the impact of energy price changes in previous periods can be useful to assess the possible result of taxes and charges. There are two main ways in which higher energy prices can affect heating energy use: (1) by inducing (short term) changes in (heating) behaviour and (2) by inducing (long term) investments in thermal insulation or energy efficient heating appliances.

International studies, for example /Dubin, McFadden 1984/, /Bernard et al. 1996/ and /Kasanen, Lakshmanan 1989/, indicate that operating costs do have an influence on the choice of heating system.

/Booij et al. 1992/ estimated the short term price elasticity of the demand for natural gas by Dutch households, using data from the period 1979-1987. They concluded that this price elasticity lies somewhere between –0.25 and –0.4, which means that a 1% price increase leads to a reduction in gas consumption of 0.25 to 0.4 %[23].

The price increases of natural gas in the Netherlands in the 1970s and early 1980s were accompanied by a strong growth in energy conservation investments, especially in the thermal insulation of existing dwellings. However, /Kemp 1995/ found only a weak relationship between the price of natural gas and the timing of such investments. /Booij et al. 1992/ also found hardly any significant impact of the gas price on investments in glass, wall, roof or floor insulation. However, they did find a significant positive relation between gas price and the *presence* of the four insulation types. An explanation for these divergent results was not given.

According to the /Ministry of Finance 1999/, the "Regulating Energy Tax", which was introduced in 1996, has had a positive impact on the financial attractiveness of energy conservation. In particular, the tax is said to reinforce the effectiveness of other instruments (including standards and subsidies) which would otherwise have performed less well due to the decreasing real energy prices. It is emphasised that the impact of the tax can not be isolated from that of other instruments, and that financial incentives alone are not sufficient: people have also non-financial motives behind their decisions to save (or not to save) energy.

In Denmark, already in the middle of the 70's fuel taxes were introduced in order to bias consumption towards other fuels than oil. In recent years, however, fuel taxes are being harmonised indicating that fuel taxes is no longer used for biasing fuel prices as a means of making it attractive for consumers to choose district heating and natural gas. In fact, the governments policy objectives, Energy 21, /Danish Energy Agency 1996/ state that it is the ob-

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[23] This estimate includes the gas consumption for other purposes than heating.

jective to continue the green tax reform in which taxes are put on environmental goods in order to decrease the marginal taxation of labour. Hence, fuel taxes are by now being applied as fiscal taxes.

For Germany a number of studies has recently evaluated the impacts of a so-called eco-tax reform (cf. e.g. the overview in /Böhringer et al. 1997/ and the contributions in /Laege, Schaumann (eds.) 1998/). However these studies are mostly operating with rather aggregated models and thus no reliable conclusions may be drawn on building heating energy efficiency.

### 5.3.2 Empirically observable effects

Evidence for Denmark and Sweden from /Leth-Petersen,Togeby 1999/ and /Kjellsson, Leth-Peterson 1999/ suggests that fuel taxes do not have a great impact on the consumption of energy in the short run as people are 'stuck' with their heating system due to substantial capital costs associated with installing heating systems. Fuel taxes may have an effect in the longer run by affecting the choice of heating systems at the building level. No empirical evidence based on Danish data exists on this matter at present. Results from the aforementioned international studies may not be valid for the Danish case, as the Danish residential energy sector is heavily regulated, cf. the development of the district heating system network and the natural gas network. Further, the ongoing harmonisation of fuel taxes, does not bring incentives towards choosing specific types of heating systems.

The empirical analysis for the Netherlands revealed a surprising *positive* relationship between real energy price and heating energy demand (/Oosterhuis, Nieuwlaar 1999/). This was caused by an unexplicably high level of energy use in one particular year. The conclusion should probably be that there is hardly any short term impact of moderate energy price changes on heating behaviour. The database used did not allow an analysis of the (long term) impact of energy prices on investments in energy conservation.

For Germany significant negative price effects are observed for one energy carrier (oil), but for district heat no significant price effect is obtained in linear formulation and for gas the price effect is even significantly positive. This may be related to the fact that regionally differentiated prices have been taken with reduced variation and probably some measurement error.

### 5.3.3 Interpretation

Changes in energy prices can have an impact on energy use in the short and the long term. The observed short term impact (on day-to-day heating behaviour) is small. The long term impact (on investments in energy conservation) is probably much larger, but hard to show statistically, because it requires the use of a model which endogenises these investment decisions. For decisions on investments actual prices may be less important than the *expectations* about the future development of prices. Timely announcements of (increases in) energy taxes are therefore likely to be recommendable.

Taxes and charges are not only *effective*, but also *efficient* policy instruments for energy conservation, at least under the assumptions of the simple model from section 5.1.1. They provide incentives to look for options to achieve the highest amount of energy saved at the lowest cost. Unlike standards and subsidies, they do not limit the range of available options. They do not force people to take unprofitable measures (as standards may do), and they do not provide "windfall gains" to people who would have taken the measures anyway (as subsidies may do). Obviously, the efficiency of taxes and charges can be limited if the system is made too complicated, leading to high costs of administration and enforcement. Also informational problems and principal-agent problems are likely to reduce the efficiency of taxes (cf. Section 5.1).

Taxes on space heating are particularly well-suited for financing purposes in the short and medium term as rather large investment costs are associated with changing the heating system or the building shell. It requires rather large investments for people in order to avoid taxes. Mostly taxes can only be avoided by installing space heating systems based on renewable energy. Thereby the residential sector carries a large share of the costs in achieving these environmental goals compared to other sectors. The social costs of this have not been evaluated. More research need to be undertaken in order to see if welfare costs are at a reasonable level.

Until recently, taxes and charges have played a minor role as policy instruments to reduce energy consumption in the countries under study except Denmark. This has changed with the introduction of the Regulating Energy Tax in 1996 in the Netherlands and the introduction of an "eco-tax" in Germany in 1999. The tax rates for fossil fuels are expected to raise further in the future. E. g., in its plans for a new tax system to be introduced by 2001, the Dutch government has expressed its intention to continue to "green" the tax system, including higher taxes on energy consumption. If these intentions will be implemented, they will certainly contribute to the financial attractiveness of further energy conservation.

In summary, fuel taxes are partially introduced as environmental taxes, but serve also as fiscal taxes. It can not in any reasonable way be stated that fuel taxes at this point are applied with the aim of affecting peoples choice of heating mode, but they contribute to increase the profitability of energy efficiency investments.

### 5.3.4 Recommendations

As explained in section 5.1, environmental taxes can be considered as the backbone of any energy conservation policy, even though they are not always sufficient on their own (because of market imperfections, because efficiency is not the only objective involved in policy making, and because their short term impact is low due to long lifespans of equipment and materials). Below, we will briefly discuss the main features of an emission/energy tax, with specific reference to their role in reducing heating energy demand in existing dwellings.

#### 5.3.4.1 Tax base and tax rate

Energy taxes can be based on a number of different parameters. If the tax is motivated by the policy objective of reducing greenhouse gas emissions, the most obvious tax base is the carbon content of the fuels used. In such cases, coal is taxed more heavily than oil, and oil more heavily than gas. The relative prices of fuels should reflect the relative benefits of reductions in carbon dioxide emissions associated with switching to these fuels.

If the tax aims at energy conservation in general, the energy content of the fuel can be used as the tax base. In practice, the tax base is often some combination of carbon and energy content.

The tax rate is usually determined by considerations concerning feasibility and political and social acceptance, rather than by the “optimum” (Pigovian) level as presented in Section 5.1.1. In reality, the “optimum” level is generally unknown and the tax level is the outcome of political negotiations. “Phasing in” a tax, by applying a rate which is gradually increasing over time, is common practice. If the tax has to serve the objective of stimulating long term investments in heating energy conservation, its introduction and changes in its rates should be announced well in advance. This enables the potential investor to make his/her decision on the basis of reliable expectations about future energy prices.

One might also consider the option of a variable tax rate. The rate can be adapted to fluctuations in (world) market prices for energy carriers, so as to achieve a more stable (or gradually increasing) price for the final consumer. In this way, the uncertainty for the potential investors is reduced: they can make their calculations on the basis of more predictable future energy prices. Obviously, there are limits to the degree to which price fluctuations can (and should) be reduced by means of such variable taxation: otherwise prices would lose their function as messengers of relative scarcity.

#### 5.3.4.2 Exemptions and reductions

Certain (groups of) energy carriers, energy users or applications can be exempted from an energy tax, or they may qualify for a reduced rate. The reason for such exemptions and reductions can be to enhance the effectiveness of the tax (in terms of energy conservation or $CO_2$ reduction), or some socio-economic reason.

If greenhouse gas reduction is the primary objective of the tax, energy from renewables (such as wind, solar power, hydropower and biomass[24]) as well as nuclear power should be exempted, as they do not lead to net $CO_2$ emissions. On the other hand, it is questionable whether energy produced by particularly energy efficient technologies, such as cogeneration and heat pumps, should be exempted from an energy tax. The tax itself should already be an incentive to use such technologies, and their exemption from the energy tax can be seen as a technology-specific subsidy, which may lead to market biases (see section 5.4).

Further differentiations are of course possible, for instance to take into account other environmental considerations. An example are the reduced taxes which some EU countries apply to heating oil with a relatively low sulfur content.

Exemptions and reductions are also being granted for socio-economic reasons, for instance to avoid competitive disadvantages for particular industries or to protect low-income households. One should always be aware of the fact that such deviations from the general energy tax create biases and price distortions and reduce the effectiveness and efficiency of the tax, because other objectives than economic efficiency are introduced, namely distributional objectives.

#### 5.3.4.3 Use of revenues

From a welfare economic point of view, there is no reason to "earmark" the revenues of an energy tax for specific purposes. The public budget is the most obvious destination for the proceeds. If the introduction of the tax, or the increase in its rates, is being compensated by reductions in other taxes, it will usually be even necessary to destine the tax revenues for the public budget. However, in some cases there may be public pressure to reserve the money (or part of it) for specific energy or environment related purposes.

#### 5.3.4.4 Monitoring, enforcement and administrative costs

Energy taxes are usually relatively easy to administer, especially if they can be linked to already existing systems (e.g. excises or public utility administrations). The costs of monitoring, enforcement and administration are generally low compared to the revenues. Possibilities for evasion or fraud are limited, particularly in the case of energy for residential heating.

#### 5.3.4.5 Side effects

Apart from leading to a reduction in $CO_2$ emissions, energy taxes can have other (direct and indirect) beneficial impacts on the environment, such as a reduction in the emission of acid-

[24] Provided that the forests or plantations from which the biomass originates are sustainably managed.

fying substances, less harm to landscape and nature from mining operations, etc.. On the other hand, to the extent that the tax stimulates the use of non-fossil fuel types of energy, the negative impacts associated with those energy sources (e.g. space use for biomass growing; adverse impacts on nature and landscape from wind and hydropower; nuclear waste and risks) will increase.

Energy taxes may spur innovations in energy technology, as they provide a continuous incentive for more energy efficient solutions. This may create competitive advantages for industries in countries pioneering with high energy taxes. Command and control instruments do not provide such incentives.

## 5.4 Subsidies

Subsidies have been rather popular for the introduction of new technologies in the past. The existing assessment studies are briefly sketched in section 5.4.1 and the outcomes of our own empirical analysis are discussed in section 5.4.2. These results are interpreted in section 5.4.3 in view of the development of recommendations for future subsidies in section 5.4.4.

### 5.4.1 Previous assessments

In the Netherlands, the large subsidy scheme under the “National Insulation Program”, which ran from 1978 until 1988, was evaluated by /SNIP 1988/. This evaluation concluded that the program had been very successful, at least quantitatively: using the subsidies (amounting to some NLG 1.6 billion), energy saving measures had been taken in more than 1.8 million dwellings. The evaluation does not assess the *effectiveness* of the subsidy schemes: it does not ask to what extent the energy saving measures would have taken place if there had been no subsidies.

An attempt to analyse statistically the impact of subsidy schemes on the diffusion of thermal home insulation in The Netherlands has been made by /Kemp 1995/. His conclusion was that subsidies for double glazing only had a small effect – if at all – on households’ thermal insulation decisions. In the case of cavity wall insulation, the effectiveness seemed to be somewhat higher, although the statistical results were not very convincing. According to Kemp, the main effect of the subsidy programmes was to provide the beneficiaries with a “windfall gain”.

/Haug et al. 1998/ estimated the impact of subsidies on the sales of condensing boilers in The Netherlands and Germany. For the Netherlands their conclusion was that in the years when subsidies were available, they led to additional sales of 46,000 condensing boilers. Given the fact that about 75,000 condensing boilers were subsidised per year, it can be concluded that almost half of the subsidy recipients were “free riders”, i.e. they would have bought a condensing boiler even if there had been no subsidy. For Germany even free rider rates of more than 50 % have been estimated.

/Creemers, B. 1999/ states that past experience shows that a subsidy of about NLG 400 (almost € 200) leads to a substantial acceleration in the rate of replacement of central heating boilers. According to him, such a subsidy led in the first half of the 1990s to an increase in the market share of condensing boilers from 15 to 50 percent.

### 5.4.2 Empirically observable effects

For Germany significant, although limited effects of subsidies can be proven empirically for single-family-buildings. For each subsidy available, the energy consumption decreases by 5.0 kWh/m$^2$. This is a rather modest decrease and for multi-family-buildings even no decrease at all can be observed.

For the other countries the impact of subsidies on investments in thermal insulation could not be assessed on the basis of the available data. For the Netherlands the main reason is the low number of observations of households investing in insulation during the period 1990-1995, as well as the poor quality of the data regarding the presence of insulation.

What the Dutch analysis does show is that the effectiveness of insulation subsidies may be reduced (as in the case of standards for new dwellings) by incomplete application or the rebound effect. This can be shown by comparing the energy savings due to insulation as observed in our sample with the theoretical savings as reported in the literature (see Table 5-2). Given that short term price effects are rather low it can be concluded that also the rebound effect is rather small. Hence the empirical results hint at an incomplete or improper application in practice.

**Table 5-2:** Theoretical and observed energy savings from four types of insulation retrofit

| type of insulation | Theoretical savings (*) | observed savings |
|---|---|---|
| glass | 11 % (**) | 9 % |
| wall | 25 % | 8 % |
| roof | 15 % | 3 % |
| floor | 7 % | (2 %)(***) |

(*) Source: /Jeeninga 1997/

(**) Only living room and kitchen

(***) Regression coefficient not significant

In Denmark subsidies are at the present time given for conversion of electrically based heating systems in areas with district heating or natural gas supply (areas covered by the gas/district heating network). Further, subsidies are given to conversion of heating systems in old houses (<1950) and old peoples houses, and installation of heating systems based on renewable energy, cf. /Leth-Petersen, Togeby 1998/. All these subsidies are related to the choice of heating system. This is because the use of CHP and thereby district heating and natural gas is seen as the cheapest way for the society to reach the enviromental goals. Effects of these kind of subsidies have not been traced in the investigation by /Leth-Petersen,Togeby 1999/. Hence, it is not possible to evaluate effects of these schemes.

### 5.4.3 Interpretation

The empirical analyses like /Leth-Petersen,Togeby 1999/ show that energy consumption per square metre is substantially higher for buildings built before 1977. One way to obtain reductions in the consumption of energy in these buildings may be to subsidise initiatives that can reduce energy consumption in these buildings. Such initiatives usually have the nature of investments and people living in these dwellings may thus be credit constrained, i.e. the investment will bring about savings that are bigger than the costs of the investment, but the investment can not be carried out because the individual is liquidity constrained. Therefore, one way of decreasing energy consumption in older buildings is to subsidise investments that reduce energy consumption by direct subsidies or tax deductions.

Further, note that special problems exist for renter occupied buildings due to regulated markets for rented flats. Building owners renting out flats are usually allowed to pass on expenses to the tenants. Thereby, they do not have any incentive to change heating system other than by facing regulation/huge subsidies. Regulation imply welfare effects as the bill is passed on to tenants. Thus, subsidies may be the way of reaching these buildings when distributional objectives are best taken into account.

However, the evidence on the effectiveness of subsidies as a policy instrument to stimulate investments in energy saving measures is scant. There are some indications that subsidies (provided they are reasonably high) may induce a larger number of people to invest in insulation or condensing boilers than would have been the case otherwise[25], but systematic evaluations of subsidy schemes are lacking. Usually, the “success” of a scheme is only measured by reporting on the amount of money that has been spent and the number of investments that have been subsidised. Thus, the *effectiveness* of subsidies remains uncertain. On the other hand, the *efficiency* of subsidies given for particular technologies is relatively low. Moreover, generic subsidy schemes are not always able to allocate the money to those applications where they will generate the highest energy savings.

The main reason for subsidies to play a role in energy saving policy is probably a political one: they are much more “popular” than taxes or standards and thus politically more feasible.

[25] For example, the abolition of insulation subsidies for owner-occupied dwellings in the Netherlands in 1982 led to a reduction in the number of insulations (SNIP, 1988).

Furthermore, they may induce “pioneers” to invest in new, relatively unknown technologies, thus setting an example. Finally, subsidies can be a suitable instrument to overcome the liquidity constraints of low-income households for investments in energy conservation.

### 5.4.4 Recommendations

As indicated in section 5.1, subsidies may be needed as an auxiliary policy instrument for several reasons. This section presents some of the main elements of subsidy schemes which influence their performance as a tool for improving heating energy efficiency in the existing dwelling stock.

#### 5.4.4.1 Eligibility

Subsidies are usually not related to the amount of energy saving realised, but to investments in particular energy saving technologies. Such subsidies work almost as command and control instruments. This implies the risk of reduced effectiveness and efficiency, because the amount of energy saving achieved by one specific type of investment can vary considerably between individual households. In order to minimise the loss of effectiveness and efficiency, it may be preferable to link the subsidy to the (calculated) energy saving which can be achieved by the investment by a “standard” household. Although one has to account for the higher administrative costs for such subsidy schemes. One could also think of a subsidy which is available only for those investments which have been selected by an independent expert as the most appropriate one (in terms of highest expected amount of energy saved per unit of total costs) in each specific case.

Alternatively, one could try to design a scheme which relates the subsidy to the energy saving which is actually achieved. Such an approach would have the advantage of providing a strong incentive for a careful, professional implementation and maintenance of the investment, so as to realise its full energy saving potential. It would also reduce the “rebound” effect. On the other hand, a higher degree of bureaucracy would be involved, because the scheme should take into account changes in household parameters leading to “autonomous” increases or decreases in energy consumption (such as family size, employment etcetera).

#### 5.4.4.2 Subsidy rates and financing

Existing subsidy schemes for energy efficiency investments in residential space heating usually apply fixed rates for a particular investment, or a certain percentage of the investment cost. Another option is pre-financing by the energy company: the company pays for the investment and the household pays a surcharge on his/her periodical energy bill, until the investment is completely paid for. The periodical amount can be calculated so as to match the expected or actual energy saving, so that the total energy bill for the household remains the same.

Energy saving subsidy schemes can be financed from the general budget, or from specific funds which may be financed by charges on energy use (such as the Dutch MAP).

#### 5.4.4.3 Monitoring, enforcement and administrative costs

Our empirical analyses strongly suggest that retrofit measures often do not lead to the amount of energy conservation which is theoretically expected. This may be due to incomplete implementation and/or the "rebound" effect. The former can be countered by independent checks on the correct installation and (where applicable) maintenance of the equipment. The latter effect may be reduced if the subsidy is in some way related to the energy saving which is actually realised (as suggested above).

The administrative costs of subsidy schemes tend to be quite high. Each individual application has to be assessed and in each case the fulfilment of all requirements and conditions of the scheme has to be checked.

#### 5.4.4.4 Side effects

Subsidy schemes are always susceptible to abuse and fraud. Adequate provisions are therefore required to make sure that the money only accrues to the eligible investments and persons.

If the subsidy is related to investments in a particular technology, a bias exists against competing technologies which may be equally or even more efficient. It is therefore important to ensure that the scheme covers the most cost-effective technology available, and that it is regularly updated so as to keep track of technological improvements. In this way, it can have a positive impact on innovation as well.

A seemingly unavoidable side effect of any subsidy scheme is the "free rider" effect: there will always be households who intended to make the subsidised energy saving anyway, and for whom the subsidy can be regarded as a gift. Excluding these households from the scheme is hardly feasible nor efficient and it would imply inequality of rights.

## 5.5 Other instruments

From the broad range of other instruments only a selection can be reviewed in the following. Again other assessments are touched upon in section 5.5.1, our own results are discussed in section 5.5.2 and interpretations are given in section 5.5.3. Finally in section 0 recommendations, particularly on audits and labels are given.

### 5.5.1 Previous assessments

Since the first oil crisis, a wide variety of awareness raising, information and counselling campaigns concerning various aspects of energy conservation have been running in the countries under consideration. The effectiveness of these actions is not always easy to determine. Usually it is measured by means of surveys which investigate (changes in) the level of people's knowledge, attitudes, motivations and intentions concerning energy conservation (/Oudshoff et al. 1997/). In some cases, attempts are made to express the effectiveness in terms of energy savings realised, although it is not always clear how these savings are estimated (e.g. /EnergieNed 1993/).

Recent research (/Steg 1999/) shows that energy use by households is mainly determined by income and household size, and much less by the degree of environmental awareness. This suggests that the influence of policy instruments aiming at increasing awareness should not be overestimated.

In Denmark a number of information campaigns and consultancy schemes have been introduced. Consultancy schemes that are designed to improve information about potential energy savings have been measured. Evidence suggests that they may have moderate effects, smaller in apartment blocks than in single family houses, cf. /Larsen, Jensen 1999/. Schemes of this type continue to work. For small houses an energy evaluation is required when the house is sold, and for large houses a scheme with yearly visits by an energy consultant is on going.

A particular type of schemes that has not been introduced so far in Denmark is heating system maintenance schemes making sure that older heating systems do not become inefficient. Such schemes are starting to be supplied by some local utilities. The development of such schemes may be introduced more generally at the national level. This is especially relevant for single family houses for which the aforementioned heating consultancy scheme is only effective when houses are sold.

In Germany such regular control (by the chimney sweep) is mandatory. Besides also many information and counselling schemes have been run by federal, regional and municipal institutions as well as by utilities. However these have declined in number and importance in the last years, as is the case in Denmark and other countries.

Recently individual metering has been introduced by law in Denmark in order to assure that consumers have incentives to save energy, including to undertake investments in climatic shields and installations of the buildings. This is particularly aiming at apartment blocks. So, the government, minister of housing, intends to use the marginal price of fuels as an instrument to upgrade insulation and installation and appliance standards. It can be questioned if the marginal fuel prices is a good device for promoting investment behaviour. At least it assumes that people are not credit constrained. If credit constraints exist then invesment behaviour must be stimulated by subsidies or other remedies that lower capital costs. Also in Germany, despite individual metering being introduced for more than a decade, the owner-tenant dilemma continues to constitute an impediment to energy efficiency investments in rented dwellings. In general inhabitants will not be able to require any of their capital costs when moving out and owners are not sure to be able to charge the investment costs to the tenant through increased bills.

### 5.5.2 Empirically observable effects

The results of our empirical analysis do not allow drawing conclusions on the effectiveness of policy instruments such as information provision and education.

However the Danish instruments of heating energy audits and energy tests have been evaluated. The results show a moderate negative influence (-2.8 kWh/m$^2$) when the building has undergone a heat audit. A somewhat more important negative impact (-7.9 kWh/m$^2$) is observed for energy-tested buildings.

### 5.5.3 Interpretation

Policy instruments aiming at improved information and awareness are probably “necessary but not sufficient”. Being well informed is a prerequisite for a household to be able to take sensible decisions on energy saving measures. This is underlined by the significant impact of the Danish information measures. A positive attitude towards energy conservation will also be a helpful factor. However, in most cases more powerful additional instruments will be needed to make the outcome of the decision process a positive one.

### 5.5.4 Recommendations

Informational schemes aiming at providing information at the individual building level have been widely applied in Denmark. Evaluation studies point at low effects of these schemes. The schemes can, however, be seen as instruments implemented to make the market mechanism work better. The same is true for the proposed Dutch Energy Performance Analysis. In this way these instruments are to be considered as necessary but not sufficient measures that improve the workings of instruments like fuel taxes or technology subsidies.

# 6 Conclusions

Today, in the European Union some 25 years of experience have been gained with policy instruments for energy saving in residential space heating. From the investigations within the EPISODE project the following major conclusions emerge regarding the research objectives stipulated in section 1 for the countries under study

## 6.1 International and interdisciplinary comparison of policy instruments

The comparison of policy instruments in use in the countries under study shows that similar types of instruments have been applied in all countries. The specific formulation of instruments however strongly depends on the national energy policy priorities and the national context concerning climatic conditions, building regulations etc.

In particular in the case of standards some convergence from bottom-up has been observed. I. e. despite the absence of co-ordinated standard setting at the European level the pace of regulation and the type of standards used has been similar. However the specific calculation and assessment methodologies used are rather different.

In recent years the use of taxes for environmental objectives has become more widespread. Whereas Denmark has applied such taxes for many years, they have been introduced or increased substantially during the last years in Sweden, The Netherlands and Germany. In France such a proposal is under discussion. Besides for environmental reasons these taxes are partly also raised for budget financing purposes.

Compared to standards and taxes the importance of subsidies and other instruments (particularly informational schemes) is lower. A broad variety of information and consultancy measures has been implemented in the different countries, with Denmark being particularly active in the field of consultancy schemes and audits and Germany showing a broad range of subsidies often given by regional and local authorities.

## 6.2 Empirical assessment of the effectiveness of policy instruments

The most obvious result of the empirical analyses is the substantial and progressive reduction in heating energy use in new dwelling vintages. To a large extent, this result can be ascribed to building standards, which have become more stringent in the course of time. Significant differences between countries occur which indicate that still some potential lies in the more thorough application of existing standards and for more tightened standards in certain countries. The observed differences between the countries can not only be ascribed to the different climate as the calculated results of the building model have shown.

Subsidies, pricing policies and taxes have also played their role in reducing (specific) heating energy consumption - to a varying extent depending on the countries. They contribute particularly in improving the profitability of investments in insulation and energy efficient boilers. Given the data sources available however these effects could only be partly assessed empirically. Other instruments, such as information provision, provide a probably indispensable support. The particularly successful Dutch case (with the highest observed reduction in specific consumption) is probably due to a balanced mix of instruments which has induced a substantial amount of energy conservation efforts.

Of course the heating energy demand does not only depend on policy instruments but also on climatic conditions and technical characteristics like the building type. Furthermore the energy demand for space heating is also influenced by the behaviour of the occupants. So besides the introduction and tightening of building standards, instruments like information, subsidies and consultancy schemes are needed to influence the energy demand depending on the behaviour.

Households living in new, well-insulated or retrofitted houses show a higher heating energy use than might be expected on the basis of building simulation models. This may be due to an imperfect implementation of the standards as well as to the “rebound effect”. Calculations of the effectiveness and efficiency of measures and instruments have to take this into account.

### 6.3 Recommendations for further regulations

With the topical focus on the reduction of greenhouse gas emissions new challenges are ahead. These require new additional efforts, whereas the limitations of energy saving policies in the area of residential space heating are also becoming visible. In many countries the residential sector has been the leading sector in the ambition to reduce carbon dioxide emissions. A thorough assessment is thus needed before pursuing this direction further.

From the investigations, a number of recommendations for EU and national authorities have been distilled that are summarised below. Furthermore, some recommendations have been added that are based on considerations regarding the position of residential space heating in the general context of energy policies.

***1. Apply carbon taxes, but do not expect them to have a large impact in the short run***

From the point of view of economic theory taxes (or emission certificates) are highly recommendable to achieve environmental policy objectives effectively and efficiently. If $CO_2$ reduction is the main objective, such taxes should preferably be related to the carbon content of the fuels. But the emission reductions to be expected through taxes in the field of residential heating until the period 2008-2012 are probably limited, given the long lifetime and renovation cycles of the building stock. Results from the empirical investigations confirm that fuel taxes have very little impact on consumption in the short run. In the long run the impact may be more substantial, in particular since they contribute to improve the profitability of investments in insulation and energy efficient boilers. To achieve the commitments under the Kyoto protocol, however, taxes will probably have to be supported by other instruments.

Furthermore, various barriers may reduce the responsiveness to the price signals that taxes provide. This is an additional reason why taxes need to be supplemented by other policy instruments.

***2. Allow flexibility in standards for new buildings***

As standards become tighter, the cost of achieving one additional unit of emission reduction increases. The need for more efficient solutions then grows. One way of achieving this efficiency is to adopt an integrated approach which takes the overall energy demand of a dwelling into consideration, including energy supply options such as renewables and cogeneration. This leaves freedom to allow for local conditions, specific features of the building, particular preferences of architects, engineers and dwellers, etc.. The Dutch Energy Performance Standard may be a useful example. Such an integrated standard can be combined with some minimum requirements regarding the individual building components and the heating system.

***3. Look especially for energy savings in existing buildings***

Results show that per square metre consumption of energy for space heating declines drastically following the introduction of restrictive building codes in the1970s and onwards. This indicates that a potential exists for reducing energy consumption in the older building stock by improving the insulation standard of building components in these buildings. One strategy could be to encourage replacement of building components in older houses, for example replacement of existing windows with low-energy windows. Another measure could be the replacement of old boilers. This measure could be forced by imposing regular controls of the efficiency of installed boilers and by fixing thresholds for their minimum efficiency as in Germany.

***4. Address specific barriers to energy savings in the existing building stock by means of appropriate supplementary instruments***

Various barriers may block the application of insulation measures and energy efficient boilers in existing dwellings. A careful analysis of these barriers is needed in order to find out which instruments (in addition to taxes and standards) are needed to overcome them. Examples may include:

- *subsidies* (including tax rebates and other schemes that reduce capital costs), if liquidity constraints are a major barrier;
- *information provision* (e.g. consultancy schemes, labelling) if a lack of information is an important barrier;

- *institutional reforms* if institutional factors are important barriers (e.g. the situation in which the investor is not able to reap the (financial) benefits from the energy saving measures due to owner-tenant relationships).

Such instruments for barrier removal have to be designed carefully so as to attain maximum effectiveness and efficiency.

***5. Design policy instruments so as to improve implementation and to reduce the "rebound effect"***

Households living in new, well-insulated or retrofitted houses show a higher heating energy use than might be expected on the basis of building simulation models. This may be due to an imperfect implementation of the standards as well as to the "rebound effect". Calculations of the effectiveness and efficiency of measures and instruments should take this into account. Policy instruments should therefore be designed so as to reduce the risk of imperfect implementation and to minimise the rebound effect if possible. One way of doing so is to look for possibilities to create a closer relationship between the (financial) incentive that the instrument provides and the actual (instead of the calculated or potential) energy saving that is realised.

***6. Introduce some harmonisation at the EU level, but do not aim at completely uniform EU wide standards***

The broad variety of standards both for calculation methodologies and building components at the European level constitutes an impediment to competition. For the calculation methodology some steps towards harmonisation have been taken (notably EN 832) but still the national heating energy requirements are not compatible. Here further steps should be taken. Furthermore, standards for measuring, calculating, verifying and communicating the energy performance of building and heating system components should be harmonised as well. The rate of an EU wide $CO_2$ tax should also preferably be uniform, so as to equalise the marginal costs of emission abatement (thus minimising total costs).

However, the *level* of energy efficiency standards should be allowed to differ within the EU. Here, harmonisation would be inefficient, given the large variety in climatic and other conditions between member states.

***7. Maximise flexibility in energy supply systems for new housing projects***

The past decades have shown that the conditions surrounding the policy area of residential space heating can change quickly and radically. Energy prices can fluctuate; technologies can improve substantially, making the older vintages obsolete; policy priorities show continuous shifts; and peoples' lifestyles and preferences are equally changeable. At the same time, new dwellings and residential areas, including their energy infrastructure, have a lifetime of at least several decades. It is therefore extremely important to follow as much as possible a “no regret” policy when deciding upon the energy supply in new housing projects. Maximum flexibility can be achieved by designing dwellings and infrastructure so as to be able to change fuels and/or heating systems in a later stage at relatively low cost. This is important with a view to the possible future introduction of renewable energy technologies. But it is also important to avoid costly investments in systems which may be relatively energy efficient initially, but are soon surpassed by other technologies.

***8. Compare the costs of energy saving in residential space heating with those in other areas***

It is certain that there is still a large potential for energy efficiency improvement in residential space heating at relatively low cost. Nevertheless, the share of space heating in households’ energy use is decreasing, both as a result of the improvements in heating energy efficiency and of the increase in energy use for other purposes (hot water, electrical appliances, transport etc.). Furthermore, it is becoming clear that the *indirect* use of energy (energy incorporated in products and services bought) is an important component of a household’s energy consumption: its share is estimated at about 60 % and it is growing. Besides heating therefore also other areas of (household) energy consumption should be looked at. A fair comparison of the costs could contribute to improved cost-effectiveness of (residential) energy saving polcies.

***9. Do not get discouraged by the limitations of the influence of energy policies on residential heating energy use***

Although the recent history has shown that considerable improvements in energy efficiency can be achieved, one should also consider the limitations of policies aiming at reducing energy demand for residential space heating. The demand for heating energy is influenced by several factors that lie largely outside the area that can be affected by public policies. Climate is the most obvious factor (apart from the human influence through greenhouse gases…). But also other important factors influencing energy use, such as income, household size and the choice of dwelling type are not suitable for interference by energy policies in a modern, democratic society and market economy. Civil rights and consumer sovereignty are likely to remain more important values than energy conservation. The scope for energy saving policies in residential space heating therefore has its limitations, although it is by no means neglgible.

## 6.4 Future applications and benefits

The results of the project EPISODE provide a thorough analysis of the effectiveness of the different policy instruments applied in the participating countries and provide an international comparison of these evaluations. The results of the project should be disseminated to:

- the European Commission services,

- the policy makers in the member states,
- energy experts in research, administration and industry.

The results can be used by the European Commission in order to define new instruments or harmonised instruments aiming at international energy policies. The analysis has also shown that a harmonisation of existing instruments in the European Union could be difficult due to national climatic or geographical differences. A harmonised building standard which is able to cope with national differences should be a research topic in the future. Also the development of an optimal policy mix requires further analyses, providing detailed insights not only on the effectiveness but also on the efficiency of the various instruments.

National policy makers can benefit from the experiences that other countries have made with their instruments which have been analysed in the framework of the project, e.g. the influence of the Danish informational schemes (energy test, heat audit). Such schemes are not existing in most countries. For both, national and international policy makers, the results provide information about the influence of the different variables on the energy use for space heating. The knowledge of these variables should enable energy experts to create instruments which account specifically for these variables. It is also possible to distinguish the effects of the different policy instruments between the short- and the long-term.

In order to provide the research results to the national and international institutions and policy makers the results should be disseminated by:

- national workshops for energy experts and policy makers,
- international workshops for energy experts and policy makers,
- publication of the report,
- articles in environmental and energy-economic journals
- the existing web-site.

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| 1 € (EUR) = | 7.43940 | DKK | (Denmark) |
| | 6.55957 | FRF | (France) |
| | 1.95583 | DEM | (Germany) |
| | 2.20371 | NLG | (The Netherlands) |
| | 8.62580 | SEK | (Sweden) |