Energy-saving potential – a case study of the Danish building stock

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Abstract
A study of data extracted from the building Energy Performance Certification scheme database reveals a great potential for energy saving in existing buildings. A building energy labelling became mandatory in Denmark[1] in 1997. Data were used to set up an energy balance for the entire Danish building stock, divided into different sectors and periods of construction. The energy-saving potential is high even considering years of campaigns promoting energy saving, the energy-saving subsidies given and building-energy-performance audits, and the fact that in Denmark the energy consumption has not increased since 1980. The general perception is that much has been achieved and generally house owners claim that they are conscious of their energy consumption, but that further investment in energy-saving measures cannot pay for itself.

This paper analyses the current energy status of the existing building stock from a scientific point of view and quantifies the national energy-saving potential by extracting data from the Energy Performance Certification scheme and combining it with data from other sources. In an analysis, where only 50 % of the least energy-efficient constructions are improved, this potential is about 30 % of the national energy consumption for space heating and 10 % of the CO_2 emission that can be related to housing. Furthermore the method is used to investigate possible paths that Denmark may follow in order to become CO_2 neutral by 2050 and how buildings can supply their share of the required savings. Identification of how to act now in order to reach the goal by 2050 by means of an acceptable investment rate for building upgrading is discussed.

The paper also discusses how knowledge recorded in the energy performance certificates can be used through different kinds of actions, ranging from promoting the Energy Performance Certification scheme to definitions of pilot projects addressing different target groups.

The Danish energy certification scheme is in agreement with the Directive on the Energy Performance of Buildings. Therefore, the procedure describing how to quantify the energy-saving potential and how to implement it in buildings can be used by other European Member States when sufficient Energy Performance Certification information is available and knowledge becomes available from central databases.

Introduction
In Denmark, approximately 30 % of the overall energy consumption is used for heating and domestic hot water in buildings. Consequently, it is of major importance to ensure that this consumption is optimised. The energy-saving potential in existing buildings was analysed to help decision-makers in their work to improve the national energy efficiency. Apart from energy considerations, the economic consequences of the energy-saving measures are evaluated.

1. Denmark has a population of approx. 5.5 million.

Table 1. The eight periods of construction and the corresponding energy-related changes in building tradition or the Danish Building Regulations' energy requirements.

Building period	Comment
1850 - 1930	shift in building tradition
1931 – 1950	cavity walls introduced
1951 – 1960	insulated cavity walls introduced
1961 – 1972	first energy requirements in BR61[1)]
1973 – 1978	tightened energy requirements in BR72[1)]
1979 – 1998	tightened energy requirements in BR78[1)]
1999 – 2007	tightened energy requirements in BR98[1)]
2007 – 2011	tightened energy requirements in BR06/08[1)]

1) *BR is a reference to the Danish Building Regulations and the following digits refer to the year when the BR came into force.*

METHOD AND DATA

The calculations of the energy-saving potential were performed using the so-called P factor or energy-profile method. This method is applicable as the calculations were made on an average building that is representative of a large number of buildings.

The building stock was divided into five types and eight periods of construction. The building typology and construction types were judged to be uniform for each period of construction. The types represented the four most common residential types, namely: detached houses, row or terraced houses, farm houses, and blocks of flats plus non-residential buildings used for trade and service (including offices). The reason for selecting these building types was that these types were the dominant building types in the database containing information collected in the course of building energy audits since 2006. The information in the database can thus be considered statistically certain. The periods were defined from acknowledged changes in building tradition in the early periods and from changes in the energy requirements stated in the Danish Building Regulations in more recent periods. The eight periods of construction and the corresponding energy-related changes in building tradition or the Danish Building Regulations' energy requirements are stated in Table 1.

To be able to evaluate the potential for energy savings, the starting point was selected from knowledge obtained from the Danish building stock register (BBR) and energy performance (EP) certificates. The energy labeling scheme for small residential buildings (EM) has been running since 1997 and stipulates that a building has to be certified whenever it is sold. In 2006, the scheme was changed according to the requirements in the European Directive on the Energy Performance of Buildings (EPBD) to a new certification procedure according to which the energy performance of all building types must be calculated. Thus information gathered during the course of building energy audits is much more comprehensive and adequate for estimating the energy-saving potential.

Data from the BBR register were collected as an extract from the national database in 2009 and give information about the size of buildings and the constructions. Information from BBR was used as background in order to create calculation models for Danish buildings in the eight typical periods regarding area, number of floors and the possibility of further insulating external walls and roofs.

EPC certificate data were organised in different databases, depending on the year of issuing the certificate. In the current investigation, certificates submitted in a period from August 2006 to December 2009 were used. Information was thus used to create models for the average insulation level of existing buildings, divided into different construction periods and building constructions.

The energy-saving potential was calculated only for buildings constructed prior to 2004, as buildings constructed in recent years were assumed to have a negligible energy-saving potential compared with the related investments.

Analyses of potential for energy saving

Upgrading the thermal envelope can give a lasting improvement of the energy performance of a building. The following analyses deal with four scenarios for building envelope improvements. The building envelope improvements were:

- Improvements addressing building envelope constructions with high U-value according to the EPC expert, who audited the building in order to issue an EP certificate. Only e constructions with the highest U-value (over the selected threshold in each scenario) were considered for improvements.
- Improvements addressing constructions that were not subject to technical, architectural or economic barriers. Thus only a limited share of each construction type was considered for improvements. This was done to adjust for insurmountable barriers in some cases, where the building stock was analysed as a whole.

SCENARIO 1 – PROFITABLE IMPROVEMENTS OF THE THERMAL ENVELOPE

In the first scenario, 75 % of all external walls with a U-value above 0.9 W/m²K were improved. The improvement equalled an addition of 100 mm mineral wool insulation material. Accordingly, 75 % of all roofs with a U-value above 0.3 W/m²K – equal to approx. 100 mm insulation material - were improved by adding 200 mm insulation material. Only 25% of the floors with a U-value above 0.5 W/m²K were improved by adding 100 mm insulation material. All windows with a U-value above 2.5 W/m²K were upgraded to 1.2 W/m²K. These limits were selected, as they were the minimum requirements defined in the Danish Building Regulations (1978).

These improvements of the entire Danish building stock within the five categories would result in energy savings equal to 37 PJ (Peta Joule) or approx. 23 % of the energy needed for

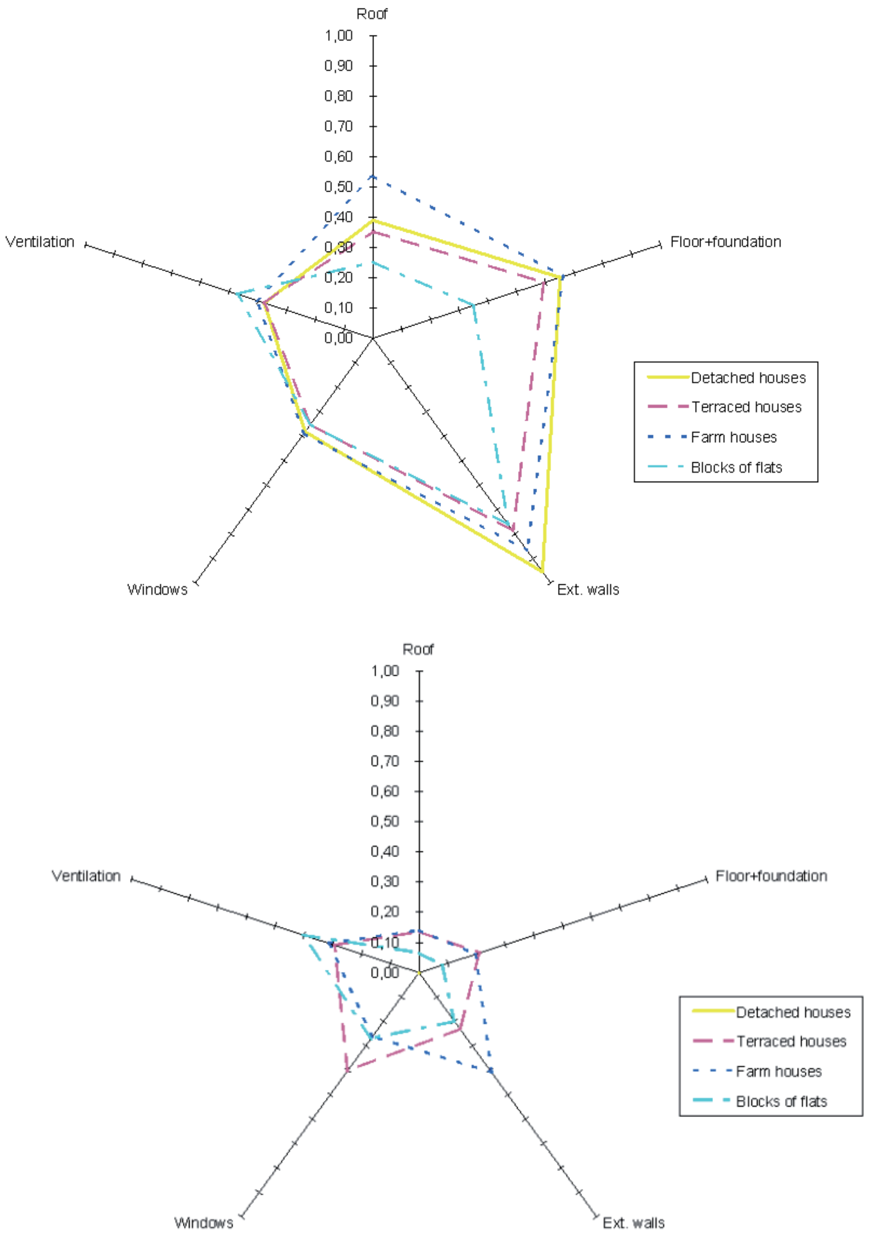

Figure 1. Examples of energy profiles (energy loss per m² heated floor area per degree temperature difference between indoor and outdoor air [W/m²K]) for residential buildings constructed in the period 1900–1930 (top) and 1998–2004 (bottom). Generally the ventilation heat loss is the single, most dominant contributor to the heat loss from buildings constructed in recent periods while loss through the thermal envelope are dominant in older buildings.

space heating and domestic hot water in these buildings. The total cost connected with these savings was estimated to approx. DKK 200 billion (approx. €26 billion). If the improvements were made in conjunction with other planned refurbishment or retrofit jobs, the additional costs was estimated to be "only" DKK 38 billion (€5 billion).

SCENARIO 2 – RADICAL IMPROVEMENTS OF THE THERMAL ENVELOPE

This scenario covered energy upgrades that could not be considered economically profitable from the house owner's perspective. These improvements would in general bring the constructions up to the same energy performance level as defined in the minimum requirement in the Danish Building Regulations (2006). Here it was assumed that all constructions with U-values above the selected threshold value were being upgraded, regardless of technical, architectural and economic barriers.

If these improvements were implemented, it was possible to obtain a total energy saving in the five building categories of approx. 58 PJ (approx. 37 % of the calculated consumption of energy for space heating and domestic hot water). The total investments needed for achieving this saving was approx. DKK 400 billion (approx. €53 billion). However, the additional cost of making the upgrading in combination with planned works was approx. DKK 100 billion (approx. €13 billion).

SCENARIO 3 – UPGRADING TO LOW ENERGY STANDARD

This scenario was a variation on Scenario 2. Here, all constructions that could not be considered to be low-energy constructions were upgraded. If this scenario was implemented, energy

Table 2. Energy-saving potential as a percentage of the energy consumption for space heating and domestic hot water when implementing profitable measures.

Building types	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Farm house	29%	27%	25%	14%	17%	14%
Detached house	34%	35%	28%	19%	22%	19%
Terraced house	30%	32%	26%	19%	17%	23%
Block of flats	32%	33%	30%	19%	22%	20%
Trade & service	32%	34%	35%	24%	24%	27%

Table 3. Energy-saving potential if the thermal envelope undergoes radical energy improvements.

Building types	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Farm house	51%	55%	52%	23%	35%	35%
Detached house	51%	51%	48%	17%	32%	20%
Terraced house	55%	57%	49%	23%	40%	23%
Block of flats	50%	51%	44%	22%	27%	22%
Trade & service	52%	54%	54%	28%	37%	36%

Table 4. Energy-saving potential if all constructions were upgraded to low energy-standard.

Building types	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Farm house	61%	62%	60%	29%	56%	60%
Detached house	60%	59%	57%	25%	55%	52%
Terraced house	63%	64%	59%	30%	58%	56%
Block of flats	55%	55%	50%	25%	38%	35%
Trade & service	60%	60%	60%	31%	48%	51%

Table 5. Energy-saving potential for the most obvious improvements.

Building types	1850-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998
Farm house	8%	8%	5%	7%	1%	2%
Detached house	7%	6%	5%	3%	2%	1%
Terraced house	8%	11%	6%	5%	3%	0%
Block of flats	9%	9%	9%	6%	3%	0%
Trade & service	9%	8%	7%	6%	4%	2%

savings of approx. 74 PJ (approx. 47 %) could be expected. The investment needed for harvesting this energy saving was estimated to approx. DKK 560 billion (approx. €75 billion), while the additional cost was estimated to approx. DKK 220 billion (approx. €29 billion).

SCENARIO 4 – MOST OBVIOUS IMPROVEMENTS

This scenario dealt only with the most obvious energy improvements of the building's thermal envelope. This meant improvements that could be considered cost effective even though they were not carried out in combination with other planned refurbishment or retrofit jobs. Here the savings potential was only about 5 % of the energy consumption in the five building categories. The investments were reduced accordingly and the needed investment was approx. DKK 32 billion (approx. €4.3 billion). The additional cost of making the improvements in combination with other works was estimated to be DDK 14 billion (approx. €2 billion).

The external walls covered by this scenario had a U-value above 1.0 W/m²K (only constructions with less than 5 cm insulation material were improved) were improved by an additional 100 mm insulation material. Of these walls, only 10 % of the total construction area was improved for architectural or technical reasons. Only 50 % of the roofs with U-values above 0.4 W/m²K, corresponding to constructions with less than 100 mm insulation material, were improved by an additional 200 mm insulation material. For the floors, only 25 % of the area with a U-value above 0.7 W/m²K (un-insulated concrete floor) was considered for upgrading by adding 100 mm insulation material. All windows, with an energy performance inferior to that of windows with double glazing, were improved to standard low energy glazing (U-value of 1.2 W/m²K).

Technical installations

Estimates of energy savings related to improvements of the technical installations were extracted from information collected from the building energy performance certification scheme. The total energy-saving potential for all five building categories added up to approx. 20 PJ of thermal energy and 0.6 PJ of electricity. The thermal energy saving equalled approx. 13 % of

Table 6. Calculated energy consumption compared with the national statement of energy consumption used for heating and hot water (Danish Energy Agency, 2009).

Building types	Calculated result	National statistics[A]	Difference	
	[TJ]	[TJ]	[TJ]	[%]
Single-family house[B]	99,788	99,179	-610	-0.6
Block of flats	37,880	38,667	787	2.1
Trade and service	21,677	21,842	165	0.8

[A]Energy consumption adjusted for climate

[B]Single-family houses include detached houses, farm houses and terraced or row houses

the energy consumption for space heating and domestic hot water in the five building types. The total cost of upgrading the technical installations was estimated at approx. DKK 36 billion (approx. €4.8 billion).

Total energy savings

The total energy savings potential by improvements of the thermal envelope and the technical installations was thus 30–35 % of the energy consumption for space heating and domestic hot water production in the affected building types.

Existing buildings' role in a fossil-fuel free society

It is the ambition of the Danish government to become a fossil-fuel-independent nation by 2050. In spite of relatively strict Danish Building Regulations governing energy consumption, the existing building stock still offers an enormous potential for achieving energy savings.

The developed calculation model was used to investigate possible paths, which could lead Denmark to become CO_2 neutral by 2050 and to illustrate how buildings can provide their share of the required savings in order to reach this goal.

CALCULATION ASSUMPTIONS

In the following the main assumptions are briefly described. For more details all the specific calculation assumptions are given in (Kragh & Wittchen, 2010).

- The saving potential was calculated for three main building categories: single-family houses, blocks of flats, and trade and service buildings.
- The buildings were divided into eight construction periods representing typical building traditions and building materials.
- The total heated area was obtained from the Building Stock Register (Danish Enterprise and Construction Authority, 2010). The heated area was adjusted for listed buildings and building areas without heating installations as such buildings obviously do not have any energy–saving potential.
- Area weighted U-values of ceilings, walls, floors and windows were obtained from the EPC scheme database.
- In the earliest construction periods the average room temperature was assumed to be 19 °C rising to 21 °C in the latest periods. In blocks of flats, the room temperature was assumed to be 21 °C in all periods.
- The average room height in residential buildings and trade and service buildings were assumed to be 2.8 and 3.0 m respectively.
- Based on previous surveys, the hourly air change rates (ach) in single-family houses were fixed at 0.35-0.45 ach, in blocks of flats 0.6–0.7 ach, and in trade and service buildings 0.5–0.6 ach.
- The hot water consumption was, based on statistics, fixed at 45 l/day per person in residential buildings and 100 l/m^2 in trade and service buildings as an average value.

VERIFICATION OF THE CALCULATION MODEL

Using data of the total building stock for the three building types, the calculation result was compared with the national statistics of energy consumption in (Danish Energy Agency, 2009) in order to verify the model. The national energy statistics result shown in Table 6 is climate adjusted.

The small difference between the calculation and the national statistics of energy consumption verifies the calculation model, see Table 6.

ENERGY MEASURES AND UPGRADING SCENARIOS

The suggested measures include energy upgrading of the entire building envelope, ventilation with heat recovery and solar heating systems for hot water production. Other renewable energy sources were not included in the model.

To investigate the energy-saving potential, three scenarios for major energy upgrading of the entire Danish building stock were assumed.

Scenario A improved the energy performance of the average existing building stock to almost the same level as required in the Danish Building Regulations (2010). Scenarios B and C improved the energy performance even further and the energy performance of the upgraded buildings would be close to low-energy building level as stated in the Danish Building Regulations (2010). The differences between the scenarios are described in the following.

Building envelope

The specific assumptions related to the insulation level of the main building construction types are shown in Table 7. In the calculation, constructions with U-value below a specific threshold value were not improved. The added insulation thicknesses were presumed to be the limit of what was feasible in practice with regard to economic and technical solutions. These assumptions of the thermal improvement of the building envelope were the same for all three scenarios.

Table 7. Scenario assumption: U-values limit of the different main envelope constructions (in brackets the corresponding insulation thickness) and the added insulation thickness or improved window U-value.

	Walls	Ceilings	Floors	Windows
U-value – threshold [W/m²K]	0.30 (100 mm)	0.30 (150 mm)	0.50 (50 mm)	1.5
Added insulation [mm] / Improved U-value [W/m²K]	200	300	100	1.0

Table 8. Scenario assumption of the percentage of the different building constructions or installations that are upgraded.

Percentage upgraded [%]	Walls	Ceilings	Floors	Windows	Ventilation	Domestic hot water
Scenario A	50	75	50	75	75 / 50[A]	50
Scenario B	75	90	75	85	85 / 50[A]	75 / 50[A]
Scenario C	85	95	85	100	90 / 50[A]	80 / 50[A]

[A]In building period 1999-2006 and after 2007 the percentage of upgraded ventilation systems and solar heating systems is assumed to be lower due to the fact that these installations already exist in many new buildings.

Technical installations

Mechanical ventilation systems with heat recovery were assumed to have an efficiency rate of 90 %. The increased electricity demands of the fans were also included in the calculation assuming a specific fan power of 1.0 kJ/m³ in single-family houses, 2.0 kJ/m³ in blocks of flats, and 2.5 kJ/m³ in trade and service buildings.

Installation of solar heating systems was assumed to reduce the energy consumption for hot water production by 70 % in single-family houses, by 80 % in blocks of flats and trade and service buildings. Solar heating used for space heating was not included in the calculation model.

Volume of upgrading

Technical, architectural and financial barriers would limit the percentage of the construction area that would in practice be upgraded. Consequently the three scenarios assume different ambitions of the percentage that was upgraded. The ambition of each scenario is presented in Table 8 and Table 7.

Calculated energy consumption

The calculated energy consumptions for heating and hot water in single-family houses, blocks of flats and trade and service buildings are presented in Figure 2 to Figure 4.

MAIN RESULTS AND CO_2 REDUCTIONS

The main results of the calculation are presented in Table 9. The table shows that Scenario A reduced the energy consumption by approximately 50 % and Scenario C, the most ambitious, by 73 %. The total energy-saving potential achieved by these very ambitious improvements of the thermal envelope and the technical installations is approx. 80–115 PJ.

The calculated CO_2 reductions in Table 9 assumed the current distribution of primary energy sources consumed in Denmark in 2009. Compared with the latest national statement of the total Danish CO_2 emission (50 Mt in 2009), these reductions account for approx. 7-10 %.

Economic investment

The investment costs of the different energy upgrading measures were found either in well-known Danish price books (Byggecentrum, 2010) or by market investigation.

The investments necessary for obtaining the savings were estimated for each scenario. In Scenario A, the total investment was calculated to be approx. DKK 500 billion (approx. €66 billion) as shown in Figure 5. If the improvements were made in conjunction with other planned refurbishment or retrofit works, the additional costs were estimated to "only" DKK 280 billion (€37 billion). It was also clear that the majority of the investments were made in the single-family houses, as shown in Figure 5. This was not due to an especially poor energy standard of Danish single-family houses, but to the fact that almost 50 % of Danes live in single-family houses.

The total cost of Scenarios B and C were calculated to be DKK 685 and 775 billion (approx. €91 and 103 billion) respectively. Similarly the additional costs were estimated to be DKK 380 and 430 billion (approx. €50 and 57 billion) respectively.

Other aspects

In the evaluation of the scenarios, we did not consider that some of the upgrading measures improved the indoor climate. Installing low-energy windows or increasing the insulation level is often found to reduce draught and mould-growth problems and thus improve the indoor climate significantly. However, the value of improved indoor climate is difficult to appraise, even though this is an important argument for the recommended energy upgrading measure. Moreover, the upgrading of the building constructions and thereby the economic value of the building was not included in the evaluation of energy-saving measures. Both aspects would obviously improve the evaluation of the energy upgrading measure.

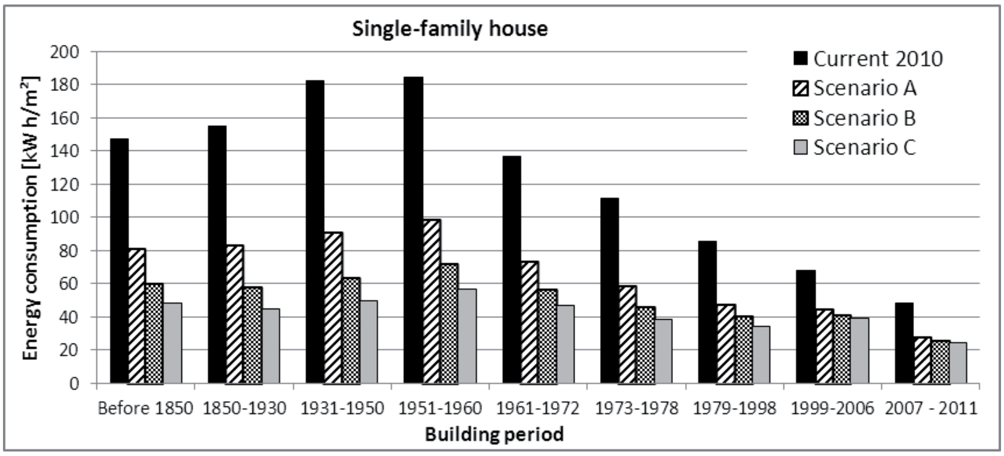

Figure 2. Calculated energy consumption in single-family houses at current energy performance level and with the energy-upgrading assumptions of Scenarios A, B and C.

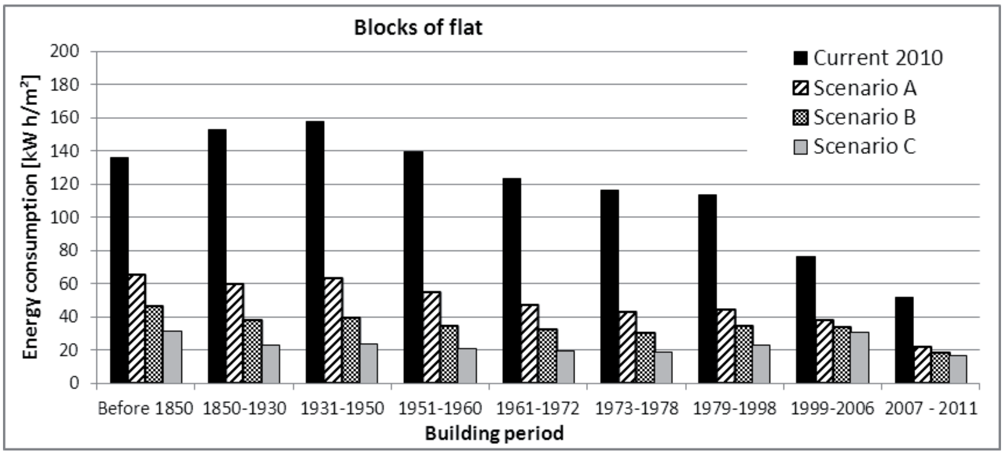

Figure 3. Calculated energy consumption in block of flats at current energy performance level and with the energy-upgrading assumptions of Scenarios A, B and C.

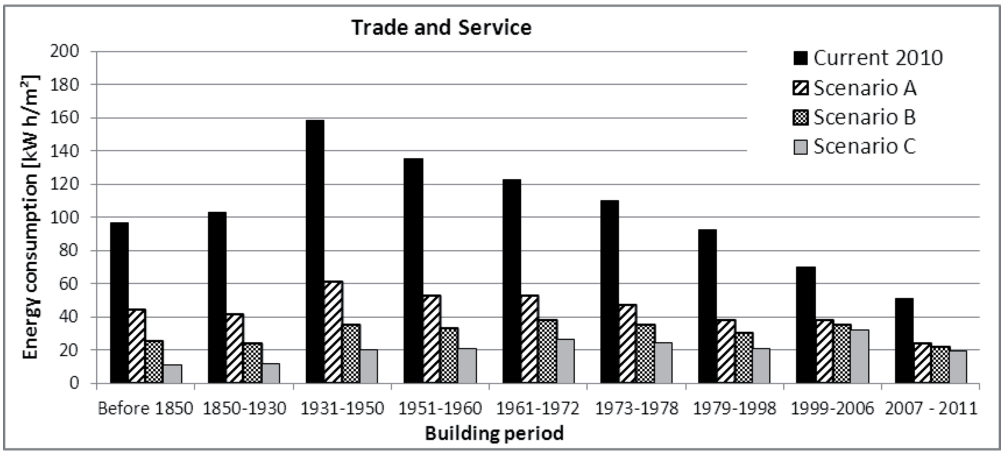

Figure 4. Calculated energy consumption in trade and service buildings at current energy building performance level and with the energy-upgrading assumptions of Scenarios A, B and C.

Table 9. Calculated annual energy savings and corresponding CO_2 reduction.

	Single-family house	Block of flats	Trade and service	Total saving		Reduction
Scenario	[TJ]	[TJ]	[TJ]	[TJ]	[%]	[Mt CO_2]
A	46,379	22,650	12,509	81,538	52	3.5
B	59,686	27,593	15,059	102,338	65	4.5
C	67,464	31,175	17,078	115,718	73	5.1

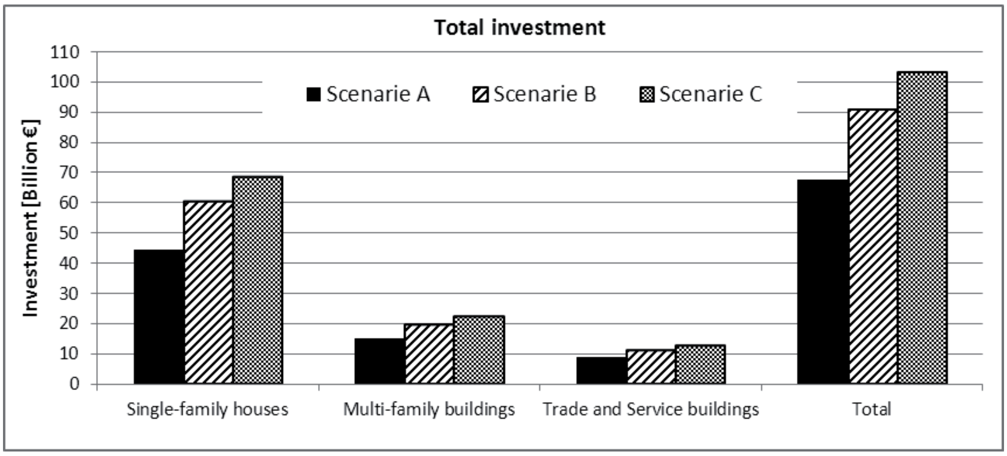

Figure 5. Total investment calculated for each building category.

Table 10. Future evaluations of the energy-saving potential in existing European buildings requires a minimum set of data to be recorded in the EPC schemes.

Building part	Minimum information to record
Building	Built-up area and heated floor area, number of floors
	Construction year and year of major upgrading
	Location of the building (climate zone)
	Recorded energy and water consumption (for comparison with calculations)
Thermal envelope	Type, area and U-value for each opaque construction type
	Area, U-value and solar energy transmission factors for each transparent element incl. any shading objects
	Thermal bridges (length/size, transmission coefficient)
	Thermal storage capacity of the building
Systems	Primary and secondary heating system (including efficiencies and location)
	Ventilation system including an estimate of the ventilation rate
	Cooling system (including Efficiency rates and location)
	Heating and cooling distribution systems (pipe length, insulation level, location)
	Domestic hot water production (including location and distribution)
Default values	Internal loads (persons, equipment, lighting, etc.)
	Domestic hot water consumption (based on persons and/or floor area)

Further possibilities for utilising recorded EPC knowledge

Working on the analyses of the potential energy savings in the existing buildings stock has provided insight into the possibilities for utilising EPC data. In this case, civil servants and politicians in the government were the target group, and the study was carried out to support their drafting of legislative incentives for energy savings and carbon reductions in the building sector. However, many other target groups are relevant when the subject is knowledge about energy-saving potential, energy efficiency of buildings, not to forget calculation of a possible carbon saving in the building stock. Among these are scientists, statisticians, local politicians, project managers, EPC experts, building manufactures, and companies involved in building energy upgrading. In other words, if organised in a well-structured database offering easy access to a wider audience, EPC data are a goldmine of information waiting to be exploited.

By implementing the European Directive on the Energy Performance of Buildings (EDPB) in 2006, Europe got an excellent opportunity to improve the general knowledge of the building stock, and in some years to perform a national evaluation of the potential for energy savings in the total existing European building stock. There is, though, some information that must be recorded in a structured way in order to enable such an evaluation. The minimum information required is listed in Table 10.

However, use of EPC data recorded in more or less centralised and more or less uniform databases have no value without an EP certificate being utilised by the building owners. The certificate must be generally accepted and regularly consulted as an important document of the building. To achieve that consciousness among building owners, data recorded in the database must rely on an EPC audit being consistently carried out. Consequently it is important that the certificate is updated in conjunction with any property transaction, by any building upgrading – and updated regularly for large buildings, even without change in ownership or user.

This can be driven by means of economic incentives, legislation and promotion of the EP certificate. At best, this will generate a self-perpetuating positive progress for the quality of EPC.

Other possibilities

There are other options for establishing a national energy balance for the existing buildings stock and thus calculate the potential energy savings. Data can be extracted from the EPC databases and combined with other sources of data. In the Intelligent Energy Europe project TABULA (Typology Approach for Building Stock Energy Assessment – 2009-2012) typical building typologies with focus on energy calculations are being established for European countries. Furthermore, a calculation tool is being developed which enables calculation of national energy balances. Further information is available at www.building-typology.eu.

Conclusions

A total energy-saving potential by means of improvements of the thermal envelope and the technical installations of 30-35 % has been identified as being economically profitable. The average, simple pay-back time for these savings is around 20-25 years. The total investment needed to harvest these savings is around €35 billion and the additional investment (when making the improvements in combination with other planned works) is limited to around €6 billion.

On average, with respect to the energy stage for the Danish building stock of the five selected building categories, it is possible to obtain a reduction of the energy consumption for space heating and domestic hot water by as much as 73 %. To attain this energy saving, an investment of approx. €103 billion is needed. If these works are made in combination with other planned refurbishment or retrofitting jobs, the additional cost of these savings will be rduced to approx. €57 billion. Making the improvements in combination with planned works thus cut the cost amost by half.

If this kind of savings is to be achieved by 2050, the average annual investments should equal 1.2 % of the Danish gross domestic product (GDP) in 2009. Combined with other planned jobs, the average annual investment would equal 0.65 % of the Danish 2009 GDP.

The credibility of these calculations relies on the quality of data recorded in national building registers, not least the database with data from reported EP certificates. This is the case by any utilisation of knowledge extracted from EPC databases. Therefore, no calculation has a higher quality than the quality of the individual EP certificate.

Consequently, high quality EPC schemes are crucial for the possibilities of using the collected information to gain additional knowledge of the building stock. Organised in a central register, the information provides valuable knowledge that can be combined with other sources of information to form the basis for all kinds of different building stock analyses.

Acknowledgements

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