Savings potential in existing Danish building stock and new constructions

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Abstract

There is a large potential for energy savings in the Danish building stock, 75% of the buildings being constructed before 1979 when the first important demands for energy performance of buildings were introduced.

The scope of this study was to investigate and set out the technical and economic potential for energy savings in the Danish building stock and in new constructions.

The study treats construction-related energy measures, incl. ventilation with heat recovery. Main focus has been on measures which are cheap to be taken when renovating or making new constructions. In order to estimate the total savings potential, detailed calculations of three typical buildings representing the building stock have been performed.

An average Danish building uses approx. 140 kWh/m^2 p.a. for space heating [1]; by implementing existing, energy-saving technologies it is possible to reduce energy consumption for space heating to 20 kWh/m^2 p.a. in a block of flats and to 40 kWh/m^2 p.a. in a one-family house. Regarding new constructions, the economically optimal insulation level is much higher than required by legislation (year 95) when evaluated over a period of 30 years.

Introduction

Normally, Denmark is considered having a relatively high insulation standard. This is also true as regards new constructions, but 75% of the existing buildings were constructed before 1979 when the first essential tightening of demands for energy performance of buildings was introduced. The energy performance of the remaining 25% of the building stock will be approx. 25-50% below the energy requirements from new regulations 2005/2006 [2]. This means that also in Denmark a big potential for energy savings exists.

In relation to the Energy Performance of Buildings Directive (2002/91/EC) different studies have been carried out on a European basis. One study coming from EcoFys [3] shows that by using existing technology, Europe could reduce greenhouse gas emissions from the building sector alone by approx. 400 million tonnes, which is more than the total EU commitment made in Kyoto! However, in order to realise this potential we need to know the potential in details nation by nation. The purpose of this study is to investigate the savings potential for Denmark.

Another important background for this study is that many of the one-family houses in Denmark erected in the 1960s are now facing a renovation: either facade or roof will be changed, not because of a poor energy performance (this may well be the case), but mainly due to a wish for a more modern design or due to general demolition. For this reason it is very important to document and ensure that “correct” architectural renovation also includes energy renovation. An upgrading of the energy performance of a construction should be done simultaneously with the general renovation, as a subsequent upgrading will be expensive. In Denmark the share of living space of one-family houses constitutes 74%.

Today, an upgrading of the energy performance is only carried out to a very small extent in existing buildings in

Table 1. Development in demand for energy performance in DK together with typical U-values of a Passive House.

U-values: [W/m²K]	BR[1] 61/72	BR 77/82	BR 95	BR 05	Passive house
Wall, heavy	1.00	0.4/0.35	0.30	0.20	< 0.15
Wall, light	0.60	0.30	0.20	0.20	< 0.10
Floor on ground/with floor heating	0.45	0.30	0.20	0.15/0.12	< 0.10
Loft/roof	0.45	0.20	0.15	0.15	< 0.10
Horizontal roof/pitch wall against roof	-	-	0.20	0.15	< 0.10
Windows (façade/roof)	2.90	2.9	1.80	1.50/1.80	0.8/1.0

[1] BR is the Danish building regulation, followed by the year of validity (e.g. 61/72). 95 is the existing regulation, and 05 is the regulation which will come into force later this year.

connection with major renovation. Some of the important barriers seem to be that people do not know and do not take interest in knowing how much energy they are using, and if people know their energy consumption, they do not know if the consumption is small or large. Beside, there seems to be a high inertia in investments which are not related to visible building improvements [4]. This means that changing the behaviour of building owners needs to be done by legislation and by effective control, as normal market forces do not exist within this area.

This paper summarises a study done at the Technical University of Denmark; the full text can be found in [2].

Method for determining savings potential

Each construction part has been analysed individually, and the most obvious possibilities for an energy-efficient renovation have been technically and economically analysed. In order to examine the effect of the individual energy-saving measures when renovating the entire building, detailed calculations have been made for three typical residential buildings: a masonry multi-storey property erected at the beginning of the 1960s, a concrete multi-storey property erected in the 1970s and a typical one-family house from the 1960s.

For new buildings typical energy-saving measures have been described, and their savings potential and possible extra costs have been estimated. The savings potential is estimated as the reduction in net energy used within the building envelope.

Method to assess cost effectiveness of energy-saving measures

Different financial methods to assess energy-saving measures exist. Often a simple payback time method is used, however, this method is not suitable for treating energy-saving measures within buildings, as it does not include important factors like increased price level of fuel, interest rate, tax and lifetime of each measure.

The evaluation of cost effectiveness of energy-saving measures is done by using the net present value (NPV). The cost effectiveness is determined by comparing the "investment profit" or NPV corresponding to the difference between the energy savings and the costs of interest on and repayment of the loan for energy-saving measures. The criterion of cost effectiveness is a positive net present value (NPV>0). The NPV typically reflects that future expenses and savings are not valuated as highly as present values. Difference in lifetime of measures is taken into consideration by introducing the necessary reinvestments and the residual value of investments at the end of the chosen calculation period.

The economically optimal solution is the one that minimises total costs of construction and heating in the considered lifetime. Normally, it can be assumed that investments in energy-saving measures in buildings result in yearly savings that are constant during the lifetime or until larger renovations are necessary. All investments and savings are calculated in prices at the time of investment, and the calculation period is 30 years.

Energy-saving measures

The basis for energy-saving measures is the heat loss from the different elements in the building envelope together with ventilation. The heat loss in the residential building stock as a whole is indicated in Figure 1 [5]. The building stock is divided into seven time-periods regarding year of construction the first three periods representing changes in style of building and the last four changes in thermal performance as demanded by regulations. The heat loss is stated in W per m² of heated floor area per temperature difference of 1K between the inside and the outside of the building (defined as the P-factor). The P-factor is calculated based on data from the central Danish register of buildings, including information on size of dwellings and type of structures.

From Figure 1 it is obvious that exterior walls cause the greatest heat loss in the oldest buildings (before 1960). This is due to well-insulated exterior walls first becoming the norm after a pronounced tightening of the requirements for thermal insulation in the building codes of 1977 following the two oil crises in the 1970s. Figure 1 also shows that the potential for reducing the heat loss through windows (when excluding solar gain) and ventilation is considerable for all buildings, and they are the largest heat-loss contributors in newly built dwellings.

Facade insulation improvement is a natural part of a facade renovation when a new rain shield is needed. Facade insulation is easy to install and is most effectively on the exterior of the structure where it is able to effectively solve

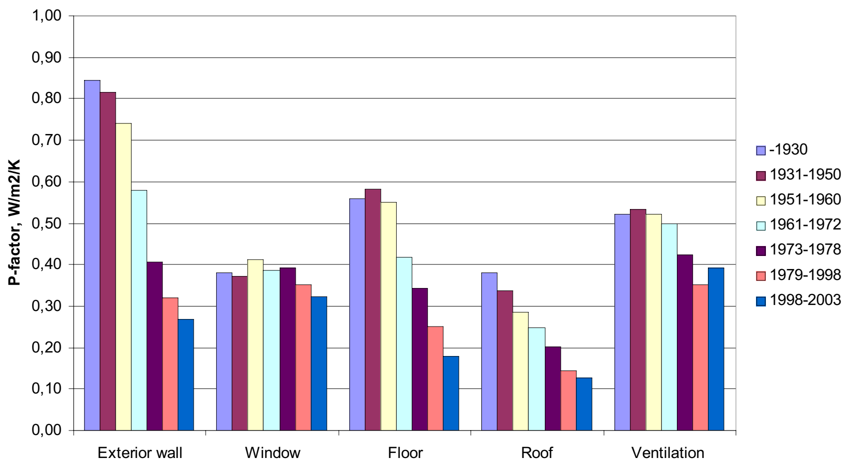

Figure 1. *Average heat loss in the residential building stock dependent on year of construction, normalised by heated floor area. Data from the energy certification scheme (1998-2003) [5].*

Table 2. Calculated space-heating demand.

Before renovation	80 kWh/m^2
After renovation	46 kWh/m^2
After renovation, with 90% heat recovery	19 kWh/m^2

mould and thermal–bridging problems. The typical insulation thickness is currently 100 mm; however, this thickness could easily be increased to twice that size. An upgrade of the energy performance of roof and ceiling is relatively simple and cheap to incorporate when renovating.

The heat transmission loss from windows with poor energy performance often constitutes a significant portion of the overall transmission loss. In general, this heat loss can be significantly reduced by switching to windows with low emission glazing and a warm edge construction. In connection with windows worthy of preservation, renovation with a second frame with energy-saving glass or a double energy-saving pane is often the optimal solution from an overall financial viewpoint.

As the ventilation heat loss is considerable, there is a potential for substantial energy savings through use of mechanical ventilation with heat recovery; ventilation losses are typically 35-40 kWh/m^2, and 80-90% can be recovered. However, this requires a good air-tightness of the building envelope in order to control the air replacement. The electricity used to run mechanical ventilation with heat recovery is in the range of 3-7 kWh/m^2.

Case study – multi-story property

The background for the actual renovation was a combination of massive problems with thermal bridges, cracks in the brickwork and closed natural ventilation openings, leading to condensation and mould growth. The renovation consists of exterior insulation of walls (150 mm) combined with a new rain screen made of thin brickwork mounted on a rail system, new windows with 1+2 glazing, a new mechanical ventilation system (exhaust only) and also a new heat-distributing system corresponding to replacement of radiators and heating pipes. The results of detailed heat-loss calculations for the actual case before and after renovation are shown in Table 2. The calculations have been made for a staircase-unit in the middle of the building. Naturally, the staircase-apartments at the building ends will have a larger heating demand.

The fairly small calculated heating demand before the renovation is primarily due to the exterior cavity wall being already insulated, though the quality of the insulation was uncertain. In general, the calculations show that it is possible to reduce the heating demand significantly. In the actual case heat recovery was not chosen although the investment had a positive NPV.

Economic evaluation and optimal "insulation thickness"

A total economic evaluation has been made corresponding to an optimisation of construction and operating costs over a 30-year period, which corresponds to the terms of a normal loan for real estate investments. The calculations have been made for two sets of interest rates and energy prices to reflect uncertainties.

Calculations of the life-cycle costs show that measures in general are cost-effective (NPV>0), Table 3. They also show that many of the measures give rise to large savings over 3 years.

The savings are however lower for the insulation improvement of exterior wall facades if the energy-saving measures bear the full costs (excluding scaffolding expenses), i.e. renovation solely in order to save energy. Facade renovation with a new weather-tight covering is, however, often used for reasons other than saving energy. In such cases it could be argued that the energy savings are a side benefit

Table 3. Total economic savings from increased insulation in typical structures in the existing stock of residential buildings. Prices are incl. VAT.

	Existing Insulation	Augmented (improved) insulation	Construction expenses	Energy savings	Predicted savings over 30 years			
	mm	mm	euro/m^2	kWh/m^2/a	euro/m^2			
Scenario					I1	I2	S1	S2
Energy price, euro/kWh					0.08	0.16	0.08	0.16
Real interest rate, % per annum					2.5	2.5	0	0
Inter-storey flooring	0	150	30.8	122	185.6	391.7	286.2	581.6
Cupboards under roof slopes	50	250	42.7	48	246.4	521.1	381.0	774.9
Sloping walls	125	225	45.6	16	52.0	132.5	102.6	217.9
Roof trusses	50	350	47.0	43	-2.8	24.6	25.7	65.1
Slab floor (joist flooring)	0	50	14.0	22	28.6	66.5	50.1	104.4
Heating pipes 1"	0	30	14.5	107	167.9	348.4	248.0	506.9
Pane replacement [1]			50.4	116	107.5	238.3	205.8	393.3
Concrete panels (res. block)	10-50	100	295.7	101	16.4	229.8	156.0	523.1
- extra insulation [2]	10-50	200	58.6	113	-14.5	9.9	10.5	52.7
Cavity wall (res. block)	40	150	319.2	117	-14.5	183.7	188.3	472.4
- extra insulation [2]	40	200	32.7	122	-13.8	-6.0	1.5	12.8
Cavity wall (SF-house)	75	150	281.6	46	-109.4	-31.2	27.6	139.7
- extra insulation [2]	75	200	10.9	49	-3.2	0.7	2.4	8.2
Solid lightweight concrete (SF-house)	0	150	281.6	94	-28.6	130.4	143.4	371.4
- extra insulation [2]	0	200	10.9	98	-1.1	5.1	5.6	14.5

1 Thermal pane replaced by an energy-saving pane.

2 Additional costs for an extra 100 and 50 mm of insulation, respectively.

Table 4. Economically optimal insulation thickness (mm) for typical constructions new buildings.

Scenario	BR98	I1	I2	S1	S2
Energy price, euro/kWh	-	0.08	0.16	0.08	0.16
Real interest rate, % /year	-	2.5	2.5	0	0
Heavy wall	125	200-250	250-325	250-325	>400
Light wall	200	250-300	325-350	325-350	>400
Loft	250	300-350	425-525	500-600	>600
Floor on ground	125	150-200	200-250	250-300	>400
Floor on ground with heating	200	200-250	300-400	>400	>400

that is free. In cases where renovation is not immediately pressing, commencing the renovation earlier could be justified because of the positive pay back time of the energy-saving measures.

In new buildings the total economically optimal insulation level is much higher than the current demand in legislation (year 95). Tabl 4 shows the economically optimal insulation thickness calculated for typical new constructions in case of different energy prices and interest rates, using a lifetime of 10 years corresponding to the lifetime of the static elements in the building envelope.

TECHNICAL SAVINGS POTENTIAL UP TO YEAR 2050

A profitable savings potential of energy used for heating of about 80% is identified over 4 years within the residential building stock if energy performance is upgraded when buildings are renovated.

The potential for profitable savings within space heating up to year 2050 has been assessed on the basis of assumptions concerning the development in building stock and energy consumption for space heating. It is presumed that the entire existing residential building stock (which in 2005 consists of 275 million m^2) will either be replaced with new buildings or thoroughly energy-renovated during the period up to year 2050. The living area is assumed to increase by 27% during the period. The presumed development in the building stock is illustrated in figure 2.

It is assumed that the energy consumption for space heating in new residential buildings will be reduced by 30% in 2005, 2010, 2015 and 2020, whereas renovated residences are assumed to be upgraded to the energy requirements applicable for new structures. Calculations on obvious energy-saving measures for both new constructions and existing buildings described in this paper support that the savings potential in these scenarios are possible technically and economically justifiable.

If the scenarios outlined are realised, it would be possible to significantly reduce the heating requirements for the building stock, Table 5. At the same time the net energy consumption for space heating would be reduced by 30% over the next 15 years and by more than 80% over 45 years (until 2050).

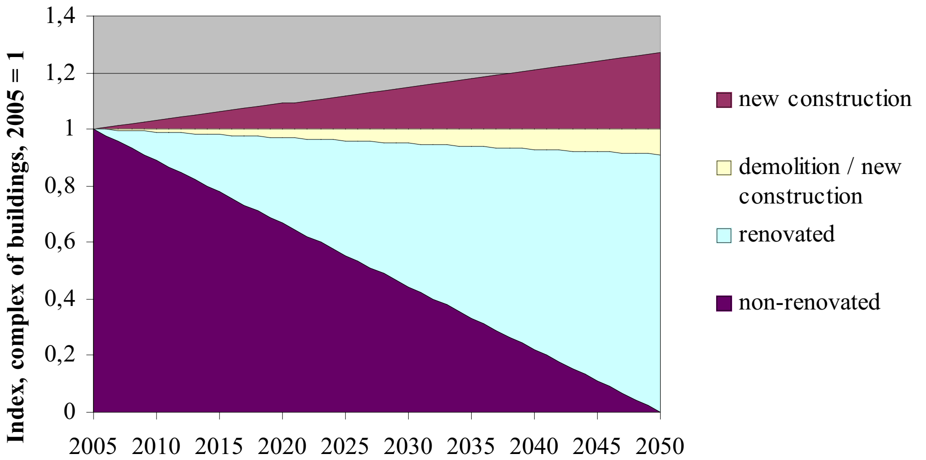

Figure 2. *Presumed development in the residential buildings stock from 2005 to 2050.*

Table 5. Development in net energy consumption for space heating in residential buildings based on the above-mentioned assumptions.

Year	Net energy consumption for space heating residential buildings [PJ/year]	Reduction in net energy consumption compared to base year 2005 [%]
2005	122	0
2020	86	-30
2030	71	-42
2050	22	-82

Future documentation

After having identified a large technical potential for profitable energy savings, the next step is to demonstrate that it is possible to achieve this in practice. Two projects have been designed to demonstrate this:

- "The easy-to-carry-out solution": the subject of this project is a typical one-family house from before 1950 where the thermal properties have not been updated. The exterior architectural appearance of this house is of high quality and may not be changed. The project shows that without changing the appearance of the house it is possible to identify several profitable energy-saving measures which have now been carried out. The effect will be documented in 2005, and calculations show an expected reduction in the energy consumption of more than 35%. The preliminary results show at this point that the NPV of the savings with a 30-year investment will be more than three times the investment cost.
- "The total solution": the subject here is a one-family house from the 1960s which calls for an architectural redesign process. The idea is to carry out a full renovation (regarding both architecture and energy), well knowing that in real life this will be done in two or three steps, and for some existing buildings part of the renovation may already have been carried out. Due to this, the project also emphasise the subject of designing a renovation plan. Preliminary results from this project are expected in 2006.

Both projects include detailed measurements of energy consumptions, indoor climate quality and air tightness before and after the renovation.

Conclusion

A profitable energy-savings potential of 82% has been identified within the Danish building stock up to year 2050; within the next 15 years the profitable savings potential is 30%. In general, building-related energy-saving measures reduce the gross energy consumption and thereby the CO_2 emissions, significantly. As the losses (from gross to net energy) when utilising the energy for space heating in general are high, this area is important in many ways. At the same time a lower level of energy consumption reduces the vulnerability to rising energy prices and increases the security of supply. The fact that Denmark is far behind the national Kyoto target focus on energy used in existing buildings might be one key to achieve the goal.

The results presented show that it is worthwhile to introduce energy-saving measures in the existing building stock; measures are in general cost-effective (NPV>0) when calculated over a period of 30 years. In addition, it is economically beneficial with larger renovations to upgrade the energy performance of the renovated parts of the buildings as much as possible and to a level that corresponds to the requirements for new constructions.

When financing energy-saving measures by normal real estate investment loans, savings can be obtained from day one and 30 years ahead, as the savings typically are larger than repayment and interest. Additional benefits are improved living conditions and secured or even increased value of the buildings.

As to new constructions there are possibilities of profitable energy savings that can reduce the energy consumption to 20% of the current level.

It has been documented that no essential barrier (neither technical nor economic) exists to realise a major part of the big energy-savings potential which have been identified. The major barrier for people not to energy-renovate their buildings seems to be lack of knowledge and interest. The market for energy savings does not react rationally on traditional market forces, such as energy price level and profitable investments, which means that legislation and control are necessary and important tools for changing the behaviour of building owners.

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