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Published in:
NSB 2014: 10th Nordic Symposium on Building Physics 15-19 June 2014 Lund, Sweden

Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Wittchen, K. B., & Kragh, J. (2014). Energy savings in the Danish building stock until 2050. In J. Arfvidsson, L.-E. Harderup, A. Kumlin, & B. Rosencrantz (Eds.), *NSB 2014: 10th Nordic Symposium on Building Physics 15-19 June 2014 Lund, Sweden: Full papers* (pp. 1277-1284). Article 159 Lunds Tekniska Högskola, LTH. Institutionen för Byggnadsteknik. http://www.nsb2014.se/wordpress/wp-content/uploads/2014/07/Complete_fullpapers.pdf

Energy savings in the Danish building stock until 2050

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KEYWORDS: *Renovation, Existing buildings, Energy savings, Regulation compliance, Energy projection*

SUMMARY: (Style: Summary Heading)
A study has been conducted analysing the energy savings for space heating and domestic hot water in the Danish building stock due to renovation of building components at the end of their service life. The purpose of the study was to estimate the energy savings until 2050 as building components are energy upgraded according to the requirements stipulated in the Danish Building Regulations 2010. Furthermore, scenario analyses was made for the potential impact on the energy consumption of introducing different levels of tightening of the energy requirements for existing buildings in the Danish Building Regulations.

Compliance with the requirements in the Danish Building Regulations will potentially result in energy savings for space heating and domestic hot water around 30 % until 2050. Further tightening of the component insulation level requirements will only result in marginally higher savings, due to the level of the current requirements. Higher energy savings can, though, be achieved e.g. by setting requirements for balanced mechanical ventilation with heat recovery and use of solar heating for domestic hot water.

1. Introduction

As something relatively new, requirements for the minimum insulation level of building components have been introduced in the Danish Building Regulations 2010 (BR10) to be applied when the building components are being renovated, e.g. replacement of roof covering. However, it is a question how much these requirements will influence the energy consumption in the existing Danish building stock in 2050. Furthermore, the impact of further tightening of the requirements needs to be investigated.

A calculation model for the net heating consumption in the entire existing Danish building stock until 2050 have been established in order to investigate the consequences of continuing with the current requirements and the effect of introducing stricter rules.

The purpose of the analyses was to clarify the energy savings until 2050 if the building components are being upgraded according to the requirements stipulated in the Danish Building Regulation 2010. Upgrading is assumed to be introduced when the building components need renovation anyway due to the building materials used having reached the end of their service life. Additionally, the analyses were targeted at an investigation of the effect of introducing stricter requirements for the energy upgrading of building components in combination with planned refurbishment.

Assumptions of when building components are going to be replaced originate from the Danish building and dwelling stock register (BBR) which holds information about the building materials used in facades and roofs. This information combined with knowledge about the age of the building and estimates for the probable service life of different building materials gives an estimate of the replacement rate and hence the rate of energy upgrading of the existing building stock.

2. Background

In the Danish Building Regulations 2010 there are ultimate minimum energy requirements that must be followed when replacing windows. For roofs, external walls etc. there are requirements that must be met if it is economically, architecturally and technically feasible to meet them as part of a retrofitting process. The examples in Table 1 are specifically listed in BR10 as normally being economically feasible.

Table 1. Examples, mentioned in the Danish Building Regulation 2010, BR10, as "often being economically feasible".

Building component	Insulation thickness that is economically feasible to upgrade [mm]	Total insulation thickness after upgrading [mm]
Accessible attic	< 175	300
Sloping walls and ceiling to ridge	< 200	300
Space under the roof slope	< 175	300
Flat roof	< 200	250
Lightweight external wall	< 150	250
Cavity masonry wall	Uninsulated	Cavity wall insulation
Massive external wall in brickwork	-	200
External wall in lightweight concrete	< 50	150
Floor structure above unheated basement	-	Insulation between beams
Floor above unheated basement	< 50	100
Floor above accessible crawl space	< 150	250
Floor above free space	< 175	300
Slab on ground	Uninsulated	250

In the analyses, the above values imply that an accessible attic is insulated if the total U-value of the roof construction is above 0.20 W/m²K, and that it will have a U-value of 0.15 W/m²K after upgrading.

BR10 also set rules for the replacement of windows, and here new windows must have an annual average energy balance of no less than -33 kWh/m² per year calculated for a standard window regarding size, configuration and average orientation. This requirement will become stricter in 2015 when the energy balance should be at least -17 kWh/m² per year, and even stricter in 2020 where the energy balance should be at least 0 kWh/m² per year. The table below shows an overview of the energy requirements for building components that should be complied with in combination with renovation and extensions of existing buildings. Compliance is mandatory unless it is not economically, architecturally or technically feasible to comply with the level of the requirements. In these cases, the building components should be insulated up to the feasible level.

Table 2. Requirements to building components in combination with renovation and extensions of existing buildings as stated in the Danish Building Regulations 2010.

Building component	W/m²K
External walls and basement walls towards the ground	0.2
Internal walls and floors towards unheated rooms or rooms heated to a temperature more than 5 K lower than the current room	0.4
Slab on ground, basement floors towards ground and floors above outdoor spaces or ventilated crawl spaces	0.12
Ceiling and roof constructions, including walls towards spaces under the roof, flat roofs and sloping walls directly towards the roof	0.15
External doors, gateways, hatches, removable windows and dome lights[1)]	1.65
Windows	**kWh/m² per year**
In facades[2)]	-33
In roofs[2)]	-10

1) When replacing windows after 1 January 2015, the U-value (incl. frame) should not exceed 1.40 W/m²K.
2) When replacing windows after 1 January 2015, the energy balance over the heating season should not be lower than -17 kWh/m² per year and for roof windows not lower than 0 kWh/ m² per year. When replacing windows after 1 January 2020, the energy balance for facade windows should not be lower than 0 kWh/m² per year.

3. Method and assumptions

The purpose of the analyses was to estimate the energy savings to be expected until 2050 if buildings and building components are being upgraded according to the requirements laid down the in the Danish Building Regulations 2010, when they have to be replaced or renovated for other reasons.

A model of the energy consumption in the existing Danish building stock was set up, based on information extracted from the database of the Danish energy performance certification scheme (EMO) and extrapolated to cover all Danish buildings using data from the Danish building and dwelling stock register (BBR). The model compares the calculated energy consumption of the building stock according to registrations made by energy certification experts with the theoretical energy consumption in the same buildings after energy upgrading. Energy flows included in the model are: space heating energy, ventilation, and domestic hot water. The calculated energy consumption for the building stock "as-is" was compared with the 2011 energy statistics by the Danish Energy Agency (Energy statistics, 2011) and showed a discrepancy of 6 % in comparable building categories.

Potential energy savings from improvements of the technical installations in the buildings are thus not part of the analyses.

Often, there will be architectural considerations in combination with external insulation of external walls made of masonry, which is the predominant building material for external walls in Denmark. This, in combination with the long service life of this kind of external walls, sets limits for the share of masonry external walls that are expected to have external insulation. For older blocks of flats in major cities constructed before 1950, there is a potential for external insulation of the walls on the back of the buildings without violating the architectural impression of the street view. The amount of this area is difficult to estimate from the available information. For other types of materials used in external walls, e.g. concrete and lightweight facades, there will normally not be the same architectural constraints against adding external insulation. It is thus assumed that 0.5 % of the masonry walls are being energy upgraded every year until 2050.

The share of energy upgrades of slabs on ground is evaluated to be modest and normally related to establishing floor heating, e.g. in bathrooms. In contrast to this, floors above basements and accessible crawl spaces are expected to be subject to energy upgrading. It is not possible to identify a certain point in the lifetime of a building when these floors will be upgraded. Therefore, it was estimated that 15 % of the floors above basements and accessible crawl spaces will be upgraded up to 2050.

3.1 Energy upgrading

The material used as roof covering is registered in the BBR. From knowledge about the year of construction and average service life of different building materials (GI, 2013), the future replacement rate of roofs are estimated and used to calculate the upgraded energy performance of the existing building stock. Roof covering of older buildings is expected already to have been replaced, but not necessarily energy upgraded, one or more times since the building was constructed. The share of these roofs that are being replaced every year is estimated to be 1 divided by the average service life of the roofing material. Similar assumptions are made for the other building components.

The insulation level for the existing building stock is based on registrations made by building experts in the building energy certification scheme. The average insulation levels were calculated for different typical construction periods and building types as area-weighted U-values.

3.1.1 Ventilation systems and solar thermal systems

Establishing balanced mechanical ventilation systems with heat recovery will have a growing relative impact as the insulation level of the buildings increases. It is therefore expected that these systems will increase in numbers over time. The effect of heat recovery was calculated by introducing an average efficiency in combination with an estimated airchange rate. It is further assumed that airtightness of the renovated buildings are being dealt with in combination with replacement of windows and external doors.

As a starting point, mechanical ventilation is not anticipated in combination with ordinary renovation works as it is not mandatory according to BR10. The effect of this measure was evaluated in a special scenario where mechanical ventilation with heat recovery was assumed to be installed in combination with replacement of roof covering of buildings with sloping roofs. The same consideration is valid for the installation of solar thermal systems for covering of a share of the energy consumption for domestic hot water.

3.2 Energy model for the existing building stock

The Danish building stock is divided into different types of buildings and furthermore into different typical age classes. Within each type and age class, the original buildings' energy performance is assumed to be more or less uniform. Based on statistical data from the EMO scheme regarding the current insulation levels and areas per unit for each of the buildings components (facades, roofs, floors, windows and doors), it is possible to create a model for each type and period, e.g. single family houses constructed between 1961 and 1972. From the calculated average energy consumption in each type and age class, it is possible to extrapolate to the consumption of the entire Danish building stock. The results of these calculations were then compared with and tuned according to the energy consumption in the same groups in the Danish Energy Agency's energy statistics (Energy statistics, 2011).

The model for the energy consumption in each class includes heat losses through the thermal envelope, ventilation losses and energy used for domestic hot water. On the gains side, loads from persons, appliances and sun through windows are included. A degree-day method was used to calculate the energy consumption in the existing building stock and for calculation of energy savings in combination with planned building refurbishment.

3.3 Service life for building materials

The service life for building components is base for the expected life time for the various building materials used for external constructions. The expected life times for building materials is extracted from GI (2013) and Larsen (1992). The life time for a material depends on many factors like roof covering, roof boarding and exposure. The average material life times are shown in the table below.

Table 3. Estimated average life times for external building materials used in the analyses.

Roof covering	Life time [years
Flat roofs	35
Asphalt board (sloping roofs)	35
Fibre concrete, incl. asbestos tiles and slates	40
Cement tiles	60
Roof tiles	60
External wall covering	
Bricks (clay, lime-sand stone, cement stone)	75
Lightweight concrete (light blocks, porous concrete)	60
Sheets of fibre cement, incl. asbestos	45
Wooden boards	40
Concrete components	40
Windows	25

For new windows, especially those made of plastic or combined wood/metal, the life time of the frame can be longer, but in this analysis it is not of major importance for the energy savings by 2050.

The figure below indicates the works associated with energy upgrading of roof insulation by 2050. The drop in activity after 2044 is due to the fact that some roof coverings are changed twice during the period and only the first replacement results in energy upgrading. Under this assumption, 81 % of the total roof area will be thermally upgraded by 2050.

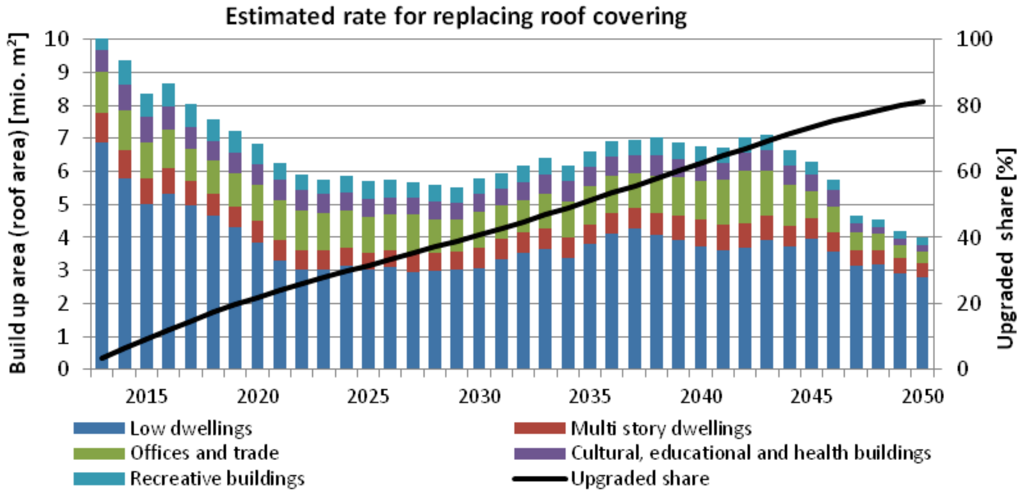

FIG 1. Estimated development in roof covering replacements that lead to energy upgrading of the roofs on the existing buildings. Over the period 82 % of the roofs are estimated to be replaced and consequently energy upgraded.

Over the period leading up to 2050, all windows are estimated to be replaced and 18 % of the external walls to be thermally upgraded. The low ratio of upgraded external walls is due to the long lifetime of the dominant masonry wall and because of architectural constraints for changing the appearance of these kinds of walls. A fixed share of 0.5 % of the available area of external masonry walls is assumed to be upgraded every year, and this dominates the total refurbishment works on external walls.

4. Calculation results

The table below shows results from 11 different scenarios. The scenarios set out to investigate the effects of different suggestions for more strict requirements to building components and other initiatives to increase energy savings in the existing building stock by 2050 and compare this with what happens if rules will remain at the same level as the current requirements. Furthermore, one scenario analysed the consequence of a prolonged service life of the roofing materials.

In the business-as-usual scenario A0, only 80 % of the potential area is assumed to be upgraded due to architectural or technical constraints. The A scenarios analyses different levels of implementing building energy upgrading by 2050. The B scenarios analyse different tightening of the component requirements in the Danish Building Regulations.

Table 4. Calculated net heating energy consumption by 2050 in each of the different scenarios.

Scenario		Energy consumption in 2050 TJ/year	Energy savings compared with today %	Energy savings compared with scenario A0 %-point
	Status 2011	206 178	-	-
A0	Business-as-usual	148 978	27.7 %	-
A1	Full BR compliance	141 446	31.4 %	3.7 %
A2	90 % BR compliance	145 212	29.6 %	1.8 %
A3	Longer life of roofs [1)]	156 072	24.3 %	-3.4 %
A4	All roofs insulated before 2050	145 943	29.2%	1.5%
A5	Fast implementation of A windows [2)]	148 978	27.7 %	0.0 %
B1	More tight requirements for roofs + A2	144 075	30.1 %	2.4 %
B2	More tight requirements for external walls + A2	143 445	30.4 %	2.7 %
B3	More tight component requirements + A2	142 308	31.0 %	3.2 %
B4	Extra tight requirements for roofs + A2	143 318	30.5 %	2.7 %
B5	Extra tight requirements for external walls + A2	141 839	31.2 %	3.5 %
B6	Requirements for A+ windows + A2	140 067	32.1 %	4.3 %
B7	Automation and effectiveness + A2	141 683	31.3 %	3.5 %
B8	Extra tight component requirements = B4+B5+B6	134 799	34.6 %	6.9 %
B9	More tight component requirements and A+ windows = B1+B2+B6	137 163	33.5 %	5.7 %
B10	Automation and effectiveness + B9	133 695	35.2 %	7.4 %
C1	BMV with VGV + B10	109 342	47.0 %	19.2 %

Faster implementation of stricter requirements when replacing windows (Scenario A5) will not result in lower energy consumption by 2050, unless new window types are invented. The reason for this is the short lifetime of windows that ensures that all windows have been upgraded to comply with the 2020 requirements before 2050 even for windows replaced in 2019.

The general insulation level of existing Danish buldings is rather high, and only a limited number of the traditional energy-saving measuers are thus economically feasible. To be able to meet the government's target that Denmark is to become free of fossil fuels by 2050 while for heating of buildings by 2035, more rigid requirements need to be considered. Among those are requirements for implementing balanced mechanical ventilation with heat recovery in residential buildings with a sloping roof (enough free space in the attic to install the ventilation system) in combination with roof retrofit (Scenario C1).

The estimated service life of roof covering materials can be questioned and a special scenario have thus been made to analyse the effects of a longer service life of these materials. A 25 % extension of the service life for roofs (Scenario A3) only results in a decrease of the retrofitted area of about 5 %, which only has a marginal influence on energy savings by 2050. Furthermore, there is a hump of roofs on buildings constructed in the 1970s, which even with a 25 % prolonged service life will need to be replaced before 2050.

The next figure shows the development of energy use for space heating, ventilation and domestic hot water in each scenario. It is clear that installation of balanced mechanical ventilation with heat recovery in combination with renovation of sloping roofs will have a significant effect on the energy consumption by 2050. This is not surprising as only a marginal share of the existing building stock has been equipped with this kind of systems yet. To be able to save this amount of energy, it is however a pre-condition that airtightness of the buildings have been improved at the same time, e.g. in combination with replacement of windows.

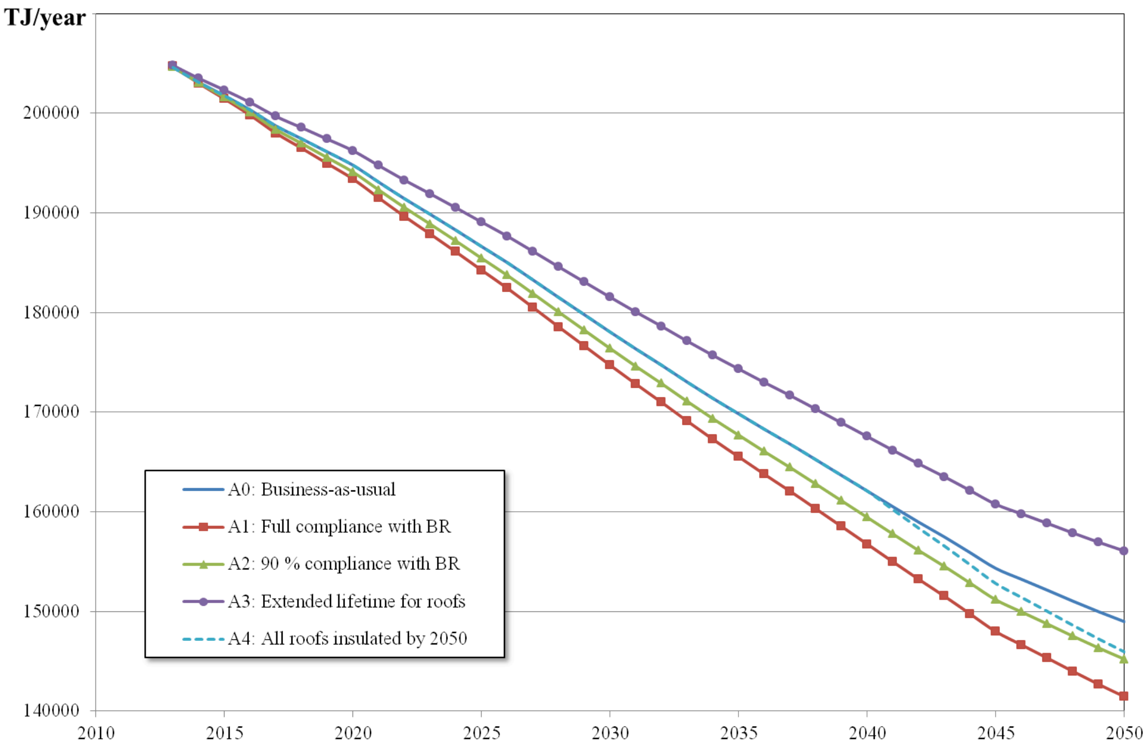

FIG 2. Development in net energy consumption for space heating, ventilation and domestic hot water in the existing Danish building stock as analysed in the A Scenarios. Energy saving measures are assumed to be implemented at the same rate as the building components are being retrofitted due to the end of their service life.

Generally, all curves bend around 2037 and that is the time when all windows have been upgraded at least once during the period, and no further energy savings can be expected from window upgrading – except if further technical improvements of window technology are implemented and requirements in the Danish Building Regulations are being tightened further.

5. Conclusions

It is the aim of the Danish government that Denmark should be free of fossil fuels by 2050 while for heating buildings this should happen in 2035. To be able to reach that goal, it is estimated that the energy consumption in the existing building stock should be reduced by about 60-70 %. Following the current path, with energy upgrading of building components in compliance with the requirements in the Danish Building Regulations 2010 (BR10) when retrofitting the buildings due to termination of service life for the building components, will not result in enough energy savings (about 30 % of the 2011 national energy use in buildings) to reach that goal.

To be able to come closer to that goal there is a need for more strict requirements in combination with refurbishment works and also improvements of the energy performance of windows. It is possible to get more energy efficient windows with an annual energy balance value of +15 kWh/m² per year for facade windows. Introduction of mechanical ventilation with heat recovery can also contribute to fulfilment of the goal.

The analyses have not taken into account demolishing of existing buildings and replacement with new buildings by 2050. Historically, about 1 % of the Danish building stock is replaced every year. If this trend continues over the next 30 years, about one third of the buildings will be newly built by 2050 and have a significant lower energy need.

6. Acknowledgements

The work has been funded as part of the Danish Energy Agency's activities for establishing a national strategy for energy upgrading of the existing building stock.

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