Potential heat savings during ongoing renovations of buildings until 2050

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Preface

Requirements relating to the post-installation insulation of building components during ongoing renovations, such as roof replacements, have been added to the Building Regulations as a relative novelty. How much would this affect net heat consumption by 2050 if the rules currently in force were to continue, and what impact would other more stringent rules have if they were added to the Building Regulations as requirements? A model has been developed to calculate the total net heat needs of the building stock with a view to answering these questions.

This report has been produced for the Danish Energy Agency following on from the work done by the Energy Renovation Network, and it is aimed at those participating in the Network, particularly the construction industry and authorities, as well as political decision-makers. In relation to the report *Heat savings during ongoing renovations of buildings until 2050* [15], the present report contains additional analyses and scenarios for various proposals to make the rules of the Building Regulations more stringent for the renovation of existing buildings.

This report is the fourth in a series on potential heat savings in existing buildings. The three previous reports are *Potential energy savings in existing buildings* [13], *Energy needs of Danish buildings in 2050* [14] and *Heat savings during ongoing renovations of buildings until 2050* [15].

Danish Building Research Institute, Aalborg University
Energy and environment
April 2014

Søren Aggerholm
Research Director

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Introduction

Aims

The aim of the calculations is to estimate the net heat saving that can be expected by 2050 if a given proportion of building components are insulated following their installation in accordance with the requirements of the Building Regulations in force on the date by which they should have undergone general renovation or replacement in any case. The calculations also show the impact of various other measures that could also be introduced to increase the stringency of the Building Regulations in connection with the renovation of buildings, such as super-energy-efficient windows and requirements concerning mechanical ventilation with waste-heat recovery.

The calculations comprise a number of scenarios. The basis for estimating the savings and costs of the various scenarios is the current composition of the Danish building stock in terms of floor area, structures, insulation, windows and ventilation system, age distribution, and use; please see the BBR Code. A number of scenarios have been set out on this basis to illustrate various challenges involved in the potential execution of energy improvements to the existing building stock.

Requirements of the Building Regulations in force concerning renovations

The Building Regulations 2010 (hereinafter BR10) [3] contain energy requirements for windows, which must be complied with when windows are replaced. It also contains requirements for roofs, external walls, etc., to the effect that profitable energy savings must be achieved if the work in question is done as part of the renovation or replacement work. The examples in table 1 are specifically highlighted in BR10 as 'often profitable'.

Table 1. Examples of 'often profitable' renovation works from the Building Regulations (BR10).

Building component	Existing insulation before renovation [mm]	Total insulation thickness after renovation [mm]
Accessible loft space	< 175	300
Slanted walls and ceilings up to the ridge	< 200	300
Roof space	< 175	300
Flat roof	< 200	250
Light external wall	< 150	250
Cavity wall	Not insulated	Cavity-wall insulation
Solid, tiled external wall	-	200
Aerated-concrete or expanded-clay concrete	< 50	150
Beam layout above unheated cellar	-	Insulation in beam layout
Floor over unheated cellar	< 50	100
Floor above accessible ventilation space	< 150	250
Floor above open space	< 175	300
Floor slabs	Not insulated	250

In the analyses, for example, the above means that an accessible loft space is insulated after its installation if the roof structure has a U value in excess of 0.20 W/m²K, and that it will have a U value of 0.15 W/m²K after the upgrade.

The Building Regulations also lay down rules for the replacement of windows. According to those rules, new windows must have an energy grant of at least -33 kWh/m² per annum, corresponding to an energy rating of C or better. It is expected that this rule will become more stringent in 2015 so that the minimum energy grant will be at least -17 kWh/m² per annum, corresponding to an energy rating of B or better, and corresponding to an energy rating of A (energy grant of at least 0 kWh/m² per annum) in 2020. The table below provides an overview of the energy requirements in the Building Regulations 2010 for building construction in conjunction with conversion, maintenance and replacement. The requirements must be met unless there are architectonic or technical construction conditions that disapply the requirement in question. Furthermore, the requirements other than those relating to windows must only be complied with if it is financially profitable to do so. The requirements must be met when building components are replaced, without any opportunity for exemption on the basis of a profitability calculation. Table 2 shows the requirements imposed on building components after renovation.

Table 2. Requirements for building components in conjunction with conversion, maintenance and replacement; please see BR10.

Building component, U	W/m²K
External walls and cellar walls adjacent to the ground	0.2
Partition walls and floor structures adjacent to spaces that are unheated or heated to a temperature more than 5 K lower than the temperature of the space in question.	0.4
Floor slabs, cellar floors adjacent to the ground, and floor structures above open spaces or ventilated guard spaces.	0.12
Loft and roof structures, including loft walls, flat roofs and slanted walls in direct contact with the roof.	0.15
External doors, gates, hatches, double-glazed windows, and skylight domes1)	1.65
Windows, E_{ref}	**kWh/m² per annum**
Facade windows2)	-33
Roof windows2)	-10

1) When skylight domes are replaced after 1 January 2015, the U value, including frames, must be no more than 1.40 W/m²K.
2) When windows are replaced after 1 January 2015, it is assumed that the energy grant during the heating season will not be more than -17 kWh/m² per annum for windows and not less than 0 kWh/ m² per annum for roof windows.

Proposals to increase the stringency of the requirements

The Energy Renovation Network's recommendations [9] and [10] indicate, among other things, the opportunities for making the energy requirements for existing buildings in the Building Regulations more stringent in connection with renovations and conversions. A number of analyses have therefore been carried out during the preparation of this report, concerning the consequences of various options for increasing stringency.

Summary and results

The report presents analyses of net heat savings related to ongoing building renovations up until 2050 if building components are insulated following their installation in accordance with the requirements of the Building Regulations in force on the date by which they should have undergone general renovation or maintenance work in any case.

The basis for estimating the savings and costs of the various scenarios is the current composition of the Danish building stock in terms of insulation and distribution according to use and age. A number of scenarios have been set out on this basis to illustrate various challenges involved in the improvements carried out or modifications made to the existing building stock.

The demolition of existing buildings that might take place by 2050 has not been taken into account. The main reason for this is that there is a great deal of uncertainty associated with information concerning demolition, including the number and energy standard of the buildings that are demolished and possibly replaced by new buildings.

The first scenario is a 'business-as-usual' scenario, which is presented as scenario A0. In this scenario, the Danish building stock is renovated according to the rate at which the individual building components wear out, and energy improvements are made to the same extent as they have been historically (over the last five years). This scenario assumes that the only work done is the work designated as 'often profitable' to execute in Annex 6 to the Building Regulations 2010. This scenario takes account of the fact that not all renovation work meets the requirements concerning post-installation insulation in practice, since an implementation rate of 80 % is used for the calculation. The 20 % that does not meet the requirements of the Building Regulations is a result of financial, architectonic or technical barriers, and a lack of willingness to comply with the rules on the part of some building owners. The significance of this is illustrated by scenarios A1 and A2, where 100 % and 90 % respectively of all renovation work is assumed to meet the post-installation insulation requirements; please see the Building Regulations.

In addition to this, a number of other scenarios have also been presented to assess different variations and combinations of scenario A0 in relation to the ways in which the energy rules in the Building Regulations will be made more stringent.

A common factor to all of the scenarios is that they show the total, cumulative net heat saving up until 2050 for the Danish building stock within the building classes that are analysed.

Results of the calculations

The following sections give the main results for the various scenarios. Table 3 shows the results for 17 scenarios where the rules in the Building Regulations are made more stringent in various ways and implemented at various rates. Please note that the total investment is the additional, energy-related investment, i.e. excluding the costs of the building site, materials that are to be used in any case (such as roofing materials), disposal, etc. It is also assumed that window prices are calculated as additional costs, since they must be replaced with C-rated windows (a minimum requirement until 2015). All of the prices in the report are given exclusive of VAT.

Table 3 Calculated net energy consumption and savings in 2050 in comparison with current consumption for the various scenarios. The financial columns show the additional energy-related investments required to achieve the savings and the cost per kWh/year saved. The highlighted fields show the combination that is carried over to the next group of scenarios.

					Dagens priser			Fremtidspriser		
Scenarie		Energiforbrug i 2050	Besparelse i forhold til 2011	Besparelse i forhold til A0	Investering i forhold til A0	Samlet investering		Investering i forhold til A0	Samlet investering	
		TJ/år	%	% -point	mio. kr.	mio. kr.	kr. / kWh pr år	mio. kr.	mio. kr.	kr. / kWh pr år
	Status 2011	206.178	-	-	-	-	-	-	-	-
A0	Business-as-usual	148.978	27,70%	-	0	140.972	8,87	0	102.472	6,45
A1	Fuld BR overholdelse	141.446	31,40%	3,70%	29.112	170.084	9,46	23.290	125.762	6,99
A2	90 % BR overholdelse	145.212	29,60%	1,80%	15.284	156.256	9,23	12.227	114.699	6,77
A3	Længere levetid af tage [1)]	156.072	24,30%	-3,40%	-1.602	139.370	10,01	-1.281	101.191	7,27
A4	Krav om tagisolering inden 2050	145.943	29,20%	1,50%	144.775	285.747	17,08	115.821	218.293	13,05
A5	Hurtig indfasning af A vinduer [2)]	148.978	27,70%	0,00%	4.418	145.390	9,15	9.955	112.426	7,08
B1	Skærpede krav til tage + A2	144.075	30,10%	2,40%	37.113	178.085	10,32	29.691	132.163	7,66
B2	Skærpede krav til ydervægge + A2	143.445	30,40%	2,70%	42.481	183.453	10,53	33.985	136.457	7,83
B3	Skærpede komponentkrav + A2	142.308	31,00%	3,20%	49.025	189.997	10,71	39.220	141.692	7,99
B4	Ekstra skærpede krav til tage + A2	143.318	30,50%	2,70%	51.396	192.368	11,02	41.117	143.589	8,22
B5	Ekstra skærpede krav til ydervægge + A2	141.839	31,20%	3,50%	55.341	196.313	10,98	44.273	146.745	8,21
B6	Krav om A+ vinduer + A2	140.067	32,10%	4,30%	43.212	184.184	10,03	20.605	123.077	6,70
B7	Automatik og effektivisering + A2	141.683	31,30%	3,50%	25.926	166.898	9,32	22.870	125.342	7,00
B8	Ekstra skærpede krav = B4+B5+B6	134.799	34,60%	6,90%	88.813	229.785	11,59	57.086	159.558	8,05
B9	Skærpede krav og A+ vinduer = B1+B2+B6	137.163	33,50%	5,70%	61.670	202.642	10,57	35.372	137.844	7,19
B10	Automatik og effektivisering + B9	133.695	35,20%	7,40%	72.312	213.284	10,59	46.014	148.486	7,37
C1	BMV med VGV + B10	109.342	47,00%	19,20%	168.650	309.622	11,51	113.450	215.922	8,03

1) Extending roof lifetime by 25 % yields a reduction in renovated roof area of only approximately 5 %, which has little bearing on the total saving in 2050.
2) Faster phasing-in of the requirement for A-rated windows will not yield an additional saving by 2050, since the windows' lifetime will be shorter than the length of time remaining when the requirement is introduced in 2015.

Danish	English
Dagens priser	Current prices
Fremtidspriser	Future prices
Scenarie	Scenario
Energiforbrug i 2050	Energy consumption in 2050
TJ/år	TJ/year
Besparelse i forhold til 2011	Saving in relation to 2011
Besparelse i forhold til A0	Saving in relation to A0
%-point	percentage points
Investering i forhold til A0	Investment in relation to A0
mio. kr.	DKK million
Samlet investering	Total investment
kr.	DKK
kWh per år	kWh per annum
Fuld BR overholdelse	Full compliance with BR
90 % BR overholdelse	90 % compliance with BR
Længere levetid af tage	Longer roof lifetime
Krav om tagisolering inden 2050	Requirement for roof insulation by 2050
Hurtig infasning af A vinduer	Rapid phasing-in of A-rated windows
Skærpede krav til tage + A2	More stringent requirements for roofs + A2
Skærpede krav til ydervægge + A2	More stringent requirements for external walls + A2
Skærpede komponentkrav + A2	More stringent component requirements + A2
Ekstra skærpede krav til tage + A2	Super-stringent requirements for roofs + A2
Ekstra skærpede krav til ydervægge + A2	Super-stringent requirements for external walls + A2
Krav om A+ vinduer + A2	Requirement for A+ windows + A2
Automatik og effektivisering + A2	Automation and increasing efficiency + A2
Ekstra skærpede krav = B4+B5+B6	Super-stringent requirements = B4 + B5 + B6
Skærpede krav og A+ vinduer = B1+B2+B6	More stringent requirements and A+ windows = B1 + B2 + B6
Automatik og effektivisering + B9	Automation and increasing efficiency + B9
BMV med VGV + B10	BMV with VGV + B10

If the trend in the renovation of roofs, facades, windows and floors continues at the pace assumed in scenario A0, the total additional costs of that work at current prices may be estimated at approximately DKK 141 billion, or approximately DKK 3.8 billion per annum. According to the Danish Construction Association, total construction activity amounts to approximately DKK 200 billion per annum, with major renovation work on the existing building stock accounting for approximately DKK 33 billion per annum.

The total investment over the period up until 2050 (future prices) is calculated in Table 3 on the basis of the expected price trend in post-installation insulation of building components, more efficient windows, and the automation and installation of balanced mechanical ventilation. The price projection appears in section *Unit prices for energy-renovation work* on page 18.

Figure 1 shows the additional investments required, as a sum for the whole period up until 2050, as heat savings per kWh per annum saved in 2050, partly for current prices and partly as a price projection until 2050.

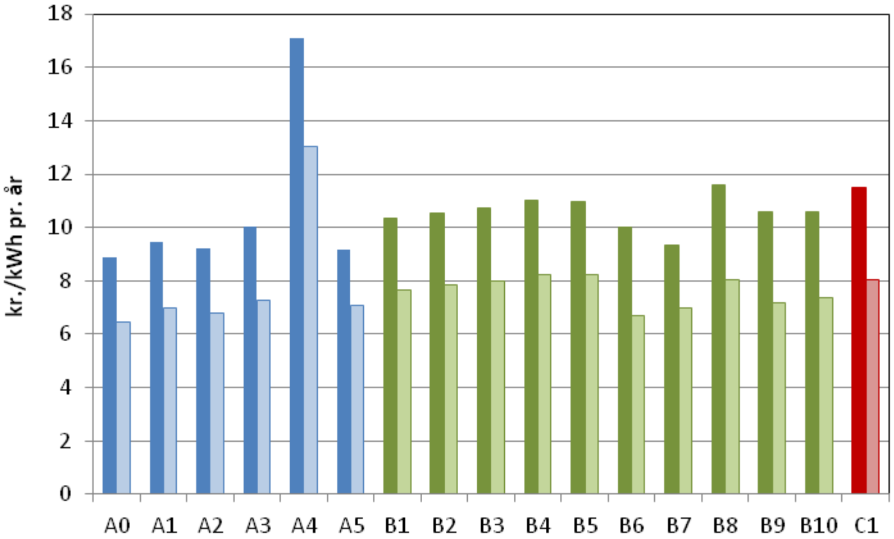

Figure 1. Investments (current and future prices (pale columns)) up to 2050 per kWh/year saved in 2050.

Danish	English
kr./kWh pr. år	DKK/kWh per annum

Figure 2 shows the projection for net energy consumption for room heating and hot water up to 2050 for selected A scenarios.

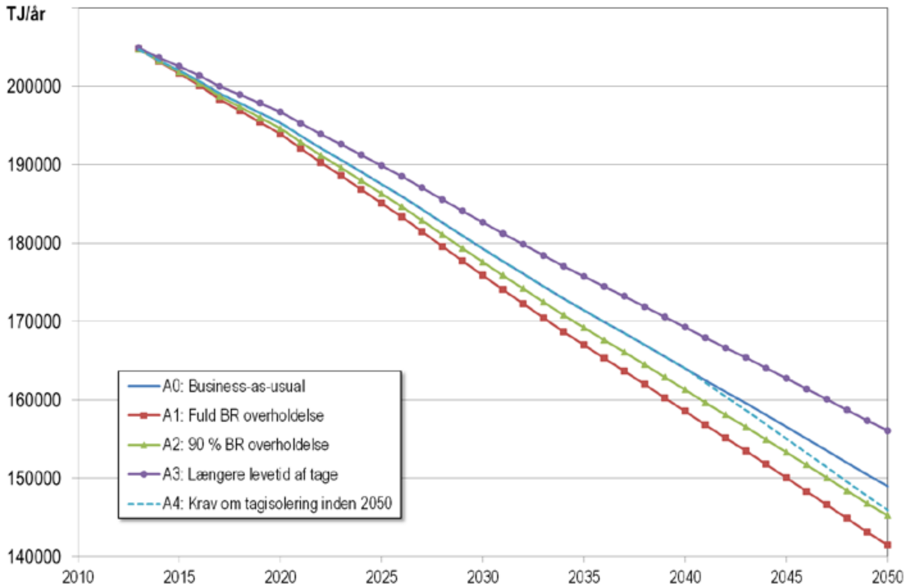

Figure 2. Trend in net energy consumption for room heating and hot water for the A scenarios. The energy-saving measures will be implemented as individual building components have to be replaced or radically renovated owing to general wear and tear.

Danish	English
TJ/år	TJ/year
A1: Fuld BR overholdelse	A1: Full compliance with BR
A2: 90 % BR overholdelse	A2: 90 % compliance with BR
A3: Længere levetid af tage	A3: Longer roof lifetime
A4: Krav om tagisolering inden 2050	A4: Requirement for roof insulation by 2050

In general, the curves will diverge in around 2037. This is because all windows will have been upgraded then and no further savings can therefore be achieved without making the requirements more stringent or improving the windows' energy performance. In addition to this, most roofs with a short lifetime will have been replaced once by that time, so they will not contribute to any further heat savings.

Figure 3 shows the projection for net energy consumption for room heating and hot water up to 2050 for selected B scenarios.

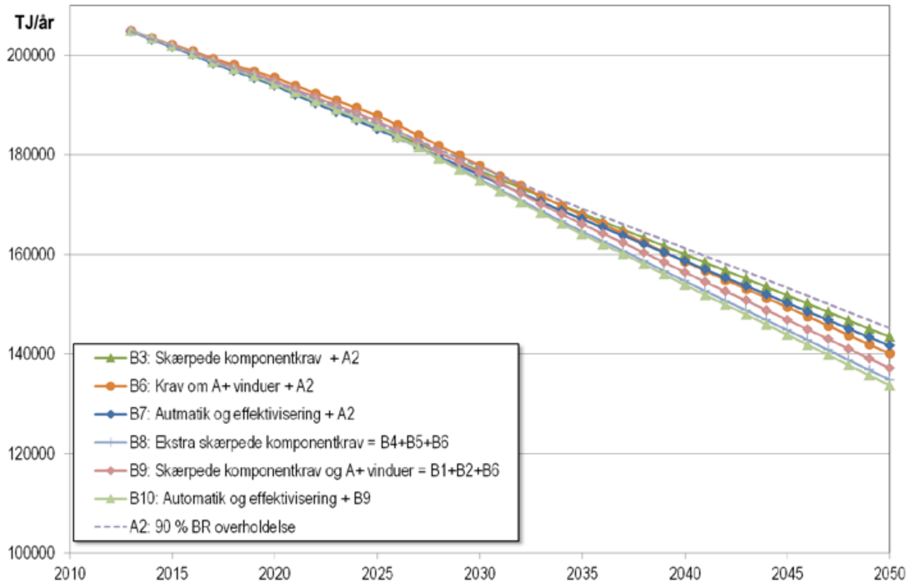

Figure 3. Trend in net energy consumption for room heating and hot water for selected B scenarios. The energy-saving measures will be implemented as individual building components have to be replaced or radically renovated owing to general wear and tear. Scenario A2, with 90 % of the component requirements for roofs and external walls, is also shown for comparison purposes.

Danish	English
TJ/år	TJ/year
B3: Skærpede komponentkrav + A2	B3: More stringent component requirements + A2
B6: Krav om A+ vinduer + A2	B6: Requirement for A+ windows + A2
B7: Automatik og effektivisering + A2	B7: Automation and increasing efficiency + A2
B8: Ekstra skærpede komponentkrav = B4+B5+B6	B8: Super-stringent component requirements = B4 + B5 + B6
B9: Skærpede komponentkrav og A+ vinduer = B1+B2+B6	B9: More stringent component requirements and A+ windows = B1 + B2 + B6
B10: Automatik og effektivisering + B9	B10: Automation and increasing efficiency + B9
A2: 90 % BR overholdelse	A2: 90 % compliance with BR

figure 4 shows that the installation of mechanical ventilation with heat recovery in conjunction with slanted-roof replacements has great additional potential for heat savings. This is natural, given that a very small proportion of the existing building stock is equipped with mechanical ventilation and that the building stock assumed for the scenarios has also undergone general improvements in the standard of insulation of the building envelope.

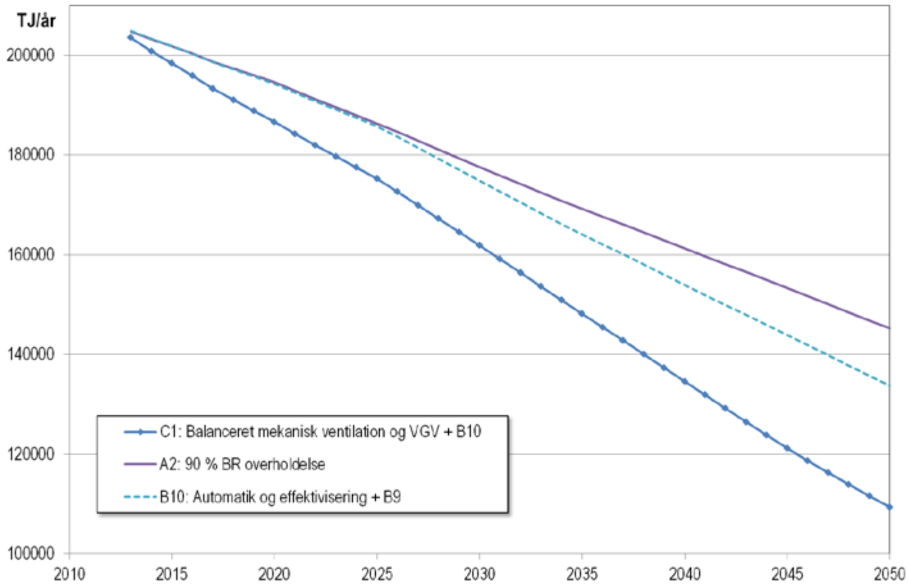

Figure 4. Trend in net energy consumption for room heating and hot water for the C scenario. The energy-saving measures will be implemented as roofs are replaced, and there is thus an obvious opportunity for mechanical ventilation to be installed. Scenarios A2 and B10 are also shown for comparison purposes.

Danish	English
TJ/år	TJ/year
C1: Balanceret mekanisk ventilation og VGV + B10	C1: Balanced mechanical ventilation and VGV + B10
A2: 90 % BR overholdelse	A2: 90 % compliance with BR
B10: Automatik og effektivisering + B9	B10: Automation and increasing efficiency + B9

Figure 5 to figure 7 show the costs over the period in question of the various A scenarios on the basis of construction activity.

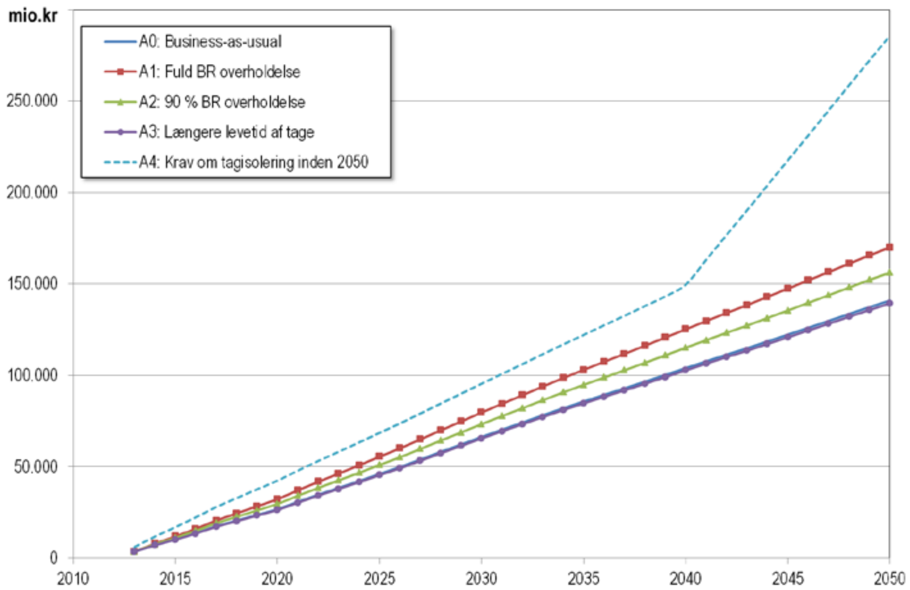

Figure 5. Costs (current prices) of the various A scenarios on the basis of construction activity.

Danish	English
mio. kr.	DKK million
A1: Fuld BR overholdelse	A1: Full compliance with BR
A2: 90 % BR overholdelse	A2: 90 % compliance with BR
A3: Længere levetid af tage	A3: Longer roof lifetime
A4: Krav om tagisolering inden 2050	A4: Requirement for roof insulation by 2050

Marginal cost of A4: The requirement for roof insulation by 2050 has been calculated so that an additional cost for post-installation insulation is only included proportionately to the residual lifetime of the roof, which will need to be replaced by the end of its lifetime. This will almost exclusively apply to slanted roofs with inaccessible cavities/loft spaces, for example where use is made of a loft space. On average, a residual lifetime of 20 % of the 60 years that constitute the lifetime of this type of roof has been used for the calculation.

The actual cost of replacing and of insulating these roofs after they have been installed and up to 2050 will still, however, equate to the full amount of replacing the roofs. The saving will therefore relate to the fact that (in principle) slanted roofs will not need to be replaced during the 2050-2071 period.

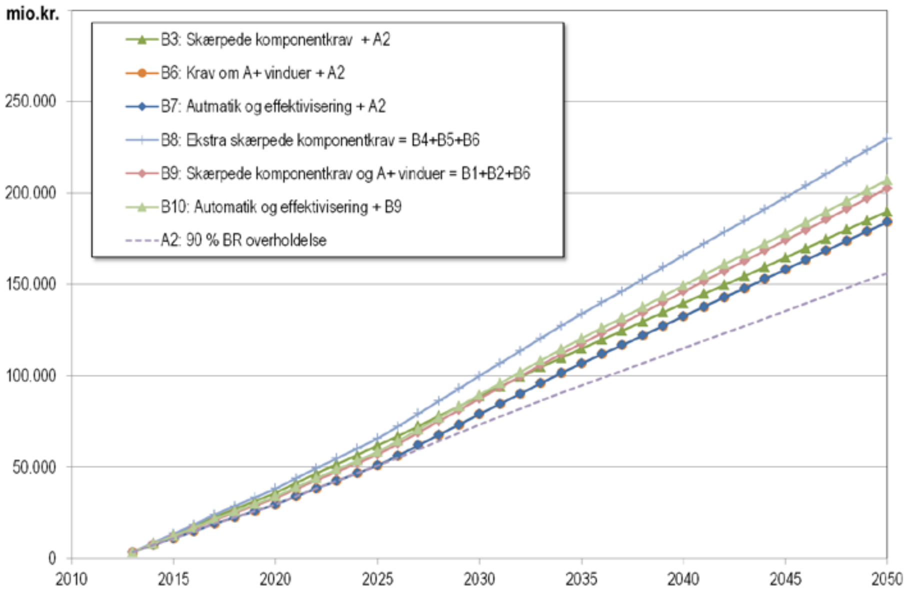

Figure 6. Costs (current prices) of selected B scenarios on the basis of construction activity. The trend for scenario A2, with 90 % compliance with the component requirements for roofs and external walls, is shown for comparison purposes.

Danish	English
mio. kr.	DKK million
B3: Skærpede komponentkrav + A2	B3: More stringent component requirements + A2
B6: Krav om A+ vinduer + A2	B6: Requirement for A+ windows + A2
B7: Automatik og effektivisering + A2	B7: Automation and increasing efficiency + A2
B8: Ekstra skærpede komponentkrav = B4+B5+B6	B8: Super-stringent component requirements = B4 + B5 + B6
B9: Skærpede komponentkrav og A+ vinduer = B1+B2+B6	B9: More stringent component requirements and A+ windows = B1 + B2 + B6
B10: Automatik og effektivisering + B9	B10: Automation and increasing efficiency + B9
A2: 90 % BR overholdelse	A2: 90 % compliance with BR

The costs associated with the installation of mechanical ventilation with heat recovery mean that it is an expensive solution, but on the other hand it yields a large heat saving. Figure 7 shows the trend in investments in the installation of balanced mechanical ventilation with heat recovery in conjunction with the renovation of slanted roofs on large buildings up until 2050.

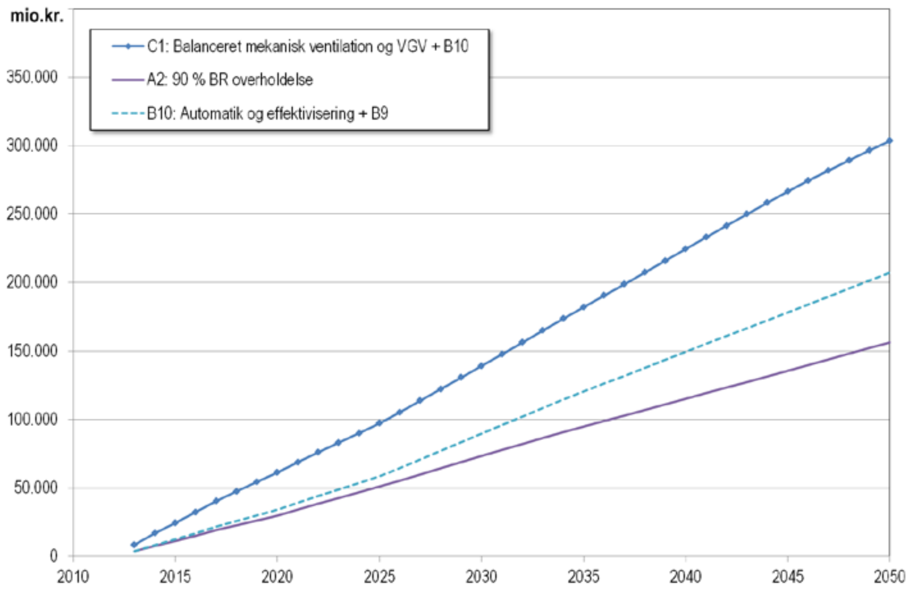

Figure 7. Costs (current prices) of the C scenario on the basis of construction activity. The trend for scenarios A2 and B10 is shown for comparison purposes.

Danish	English
mio. kr.	DKK million
C1: Balanceret mekanisk ventilation og VGV + B10	C1: Balanced mechanical ventilation and VGV + B10
A2: 90 % BR overholdelse	A2: 90 % compliance with BR
B10: Automatik og effektivisering + B9	B10: Automation and increasing efficiency + B9

Methods and assumptions

The aim of the analysis is to estimate the net heat saving that can be expected by 2050 if a given proportion of building components are insulated following their installation in accordance with the requirements of the Building Regulations in force on the date by which they should have undergone general renovation, replacement and maintenance work in any case. The calculations also show the impact of various other measures that could also be introduced to increase the stringency of the Building Regulations in connection with the renovation of buildings, such as super-energy-efficient windows and requirements concerning mechanical ventilation with waste-heat recovery. The calculated net heat saving corresponds to the reduction in heat and ventilation loss from the buildings, including energy consumption for the heating of domestic water.

The calculated net heat need for the building stock in 2012 that is used for homes is compared to the equivalent amount from the Danish Energy Agency's energy statistics [7] and shows a deviation of approximately 6 %, which is considered to be acceptable. The heat consumption that has been calculated cannot be expected to be equally appropriate for other building categories, since there are far greater differences in the consumption pattern than there are for homes. This fact does not have any great impact on the relative savings that have been calculated. The heat consumption that has been calculated has therefore been used as the basis for calculating the savings.

The analyses only include net heat savings, so the impact of an energy upgrade to the buildings' energy supplies is not included. A mean estimate could, however, be made at a later stage, on the basis of the net heat needs of the renovated buildings.

The building components included in the survey in this context are roof structures, external walls, floors and windows.

Ongoing energy improvements

There will usually be architectonic considerations related to the external, post-installation insulation of tiled external walls. This, combined with a long mean lifetime for wall construction, means that the scope of ongoing renovations for external walls of this kind is considered to be relatively modest. In the case of older floor structures dating back to before 1950, there will often be potential for the post-installation insulation of external walls adjacent to the back garden, without this having any impact on the overall architectonic impression of the townscape. It is, however, difficult to estimate the scope of this external-wall area on the basis of the information in the Buildings and Homes Register (BBR) [2]. Other external walls that are made of concrete or light concrete, on the other hand, could be renovated more frequently than tiles, and there will not usually be the same level of caution here in relation to external post-installation insulation. External walls with light cladding (slabs or timber) are assumed to be insulated following installation as general replacements are carried out, depending on the lifetime of the cladding in question.

The type of roof material used on a building is recorded in the BBR. The future replacement date may be estimated on the basis of the year in which the building was erected and the mean lifetime of the type of roof cladding in question. The roof-cladding materials used on older buildings may be assumed to have been replaced once or more already since erection of the building, and they are considered as a whole. The proportion of materials replaced each year is assumed to be the reciprocal value of the lifetime of the roof-cladding type in question. A similar method is used for other building structures.

The extent to which floor slabs are insulated following their installation is assumed to be modest and often connected to the installation of floor heating, for example in bathrooms. In contrast, however, floors over unheated cellars or ventilation spaces may be expected to be covered to some extent by ongoing renovations or improvements to the buildings in question. It is not possible to identify a specific point in the lifetime of a building when this work will be carried out, so it is assumed that 15 % of uninsulated floors over cellars and ventilation spaces will be insulated and that they will be distributed evenly over the period up to 2050.

The existing level of insulation is based on the records collected in connection with the energy labelling of buildings. A mean insulation level (area-weighted U values[1]) is calculated for the specific construction periods and types of building use.

Ventilation facilities

The establishment of mechanical ventilation with heat recovery will increase in its relative importance as the insulation standard of the building envelope rises. This initiative may therefore be expected to be used more frequently. The impact of mechanical ventilation with heat recovery is calculated by introducing a mean efficiency of heat recovery and associated exchange of air. It is assumed that the rest of the building is impervious to accidental infiltration in connection with the replacement of windows and external doors.

It is essentially assumed that mechanical ventilation is not installed during the renovation of existing buildings, since the Building Regulations do not contain any such requirement. The impact of this is estimated in scenario C1, where ventilation facilities with heat recovery are considered for installation only during roof renovation/replacement on buildings that have a slanted roof.

Energy model for the building stock

The building stock is divided into classes on the basis of typical construction periods and the types of use included in the BBR. A model for unit consumption in each class, e.g. single-family homes built in 1961-1972, is propounded on the basis of statistical data printed out from the database used for the energy-labelling scheme, concerning the current insulation standard of the building and the area of the building components per unit area (heated floor area). It is possible to extrapolate heat consumption to the total area (recorded in the BBR) in each class on the basis of the mean heat consumption in each class. The results of the extrapolated heat consumption are compared to the Danish Energy Agency’s energy statistics [7] to ensure that the order of magnitude is correct for the initial situation before any calculations are performed to ascertain the potential for savings in connection with other planned renovation work.

The model for unit consumption in each class includes heat loss through the building envelope, through ventilation, and to domestic hot water. It also includes contributions to the heating of the buildings in question, in the form of heat released by people and by electrical installations, and solar radiation

[1] Calculated as an area-weighted mean for all structures erected during a given construction period.

through the windows of the buildings in question. A degree-day method is used to estimate heat consumption in the current building stock.

The same model is also used to estimate the potential for heat savings, since improved insulation capacity is implemented as some of the buildings undergo renovations. The model may also include the impact of installing mechanical ventilation with heat recovery.

Lifetimes

The expected lifetimes of building components are based on mean values taken from www.levetider.dk [8]. The lifetime of an element such as roof cladding depends on many factors, such as the roof pitch and underlayment type. This analysis uses the lifetimes of typical structures and external climate conditions. The mean lifetimes that have been assumed are given in table 4.

Table 4. Estimated mean lifetimes based primarily on www.levetider.dk [8].

Roof cladding	Lifetime [years]
Built-up (flat roof)	35
Felt board (with roof pitch)	35
Fibreglass cement, including asbestos (corrugated or slate asbestos cement)	40
Breeze block	60
Tiles	60
External-wall cladding	
Bricks (tiles, sand-lime bricks, and breeze block)	75
Light concrete (light stone blocks and aerated concrete)	60
Fibreglass-cement slabs, including asbestos (asbestos cement, etc.)	45
Timber cladding	40
Concrete elements	40
Other	
Windows	25
Heat-producing facilities	20

As may be seen, a mean lifetime of 25 years has been used for existing windows. For new windows (especially those made of plastic or timber/aluminium), the lifetime of the actual frame may be somewhat longer, but it is not crucial for the potential savings in this analysis, since replacing windows again during this period will not yield any further saving if the replacement window is of the same energy quality, for example if an A-rated window is installed in 2022 and replaced again in 2047.

Unit prices for energy-renovation work

The financial costs of the energy-saving initiatives in terms of current prices are based on prices taken from the online edition of the V&S price catalogue for 2012 [12].

Since the initiatives are carried out during other planned renovations of the same building component, only the price of the energy-saving initiative itself has been included. Accordingly, only the price of post-installation insulation work has been included with regard to the replacement of roof cladding, for example. As far as roofs are concerned, this means the removal of old insulation, the supply and assembly of battens and insulation with cross-insulation, the raising of trusses, and the laying of new trestles.

The costs will depend on the scope of the work. The impact of this has been included by using the price that applies to the mean building size in each category (use and construction period). It does not have as great an impact in relation to single-family dwellings of nearly identical mean size (please see table 12 on page 31) in all construction periods, but it could be of somewhat greater significance for other types of building.

A certain trend in the prices of post-installation insulation work may be expected up to 2050 as a result of technological development and the rationalisation of various work processes. It is not immediately possible to provide a sure estimate for this trend, but for the purposes of calculating the financial impact in terms of future prices it has been assumed that the price of post-installation insulation of building structures will fall by 20 %. A 30 % fall in prices is assumed for improving efficiency, automation and mechanical ventilation. In all cases, the fall in prices is assumed to be distributed equally over the 2020-2040 period so that it does not achieve its full impact until 2040. The price of windows is assumed to follow the trend described on page 22.

The background report for the Energy Renovation Network to use in its work estimates the potential technical development of various solutions for energy upgrades to existing buildings [11]. With regard to insulation materials, the trend is expected to reduce their thermal conductivity to 0.017 W/mK. Lower thermal conductivity may mean that the same insulation level (U value) can be achieved using a smaller insulation thickness. This has a positive impact on structures where the insulation thickness constitutes a technical problem for construction, or where there is limited space. It is uncertain whether improving the insulation capacity of insulation materials will offset the total costs of achieving a given insulation standard. The price of surface cladding will remain unchanged, while the price of battens or latches will fall as a result of the smaller dimensions required. It is, however, uncertain whether this will be enough to offset any increase in the prices of insulation materials for the total degree of insulation. The development of better insulation materials will not, however, achieve its greatest impact until the U-value requirements of the Building Regulations are made more stringent. No particular price impact has been calculated for this.

Roofs/lofts

Figure 8 and figure 9 show the marginal cost of post-installation insulation of roofs in connection with the replacement of roof cladding, and of the post-installation insulation of accessible loft spaces. The price includes the removal of existing insulation (approximately 70 mm), the supply and laying of roof battens, post-installation insulation equivalent to the insulation level specified in table 1, with insulation slabs and the establishment of wind barriers. The difference in price between newer and older roofs is due to the fact that trusses in older roofs usually consist of square beams, whereas newer roofs consist of higher, rectangular beams.

Figure 8. Marginal cost of post-installation insulation of roofs in connection with the replacement of roof-cladding materials.

Danish	English
Tag	Roofs
Marginalomkostning [kr./m^2]	Marginal cost [DKK/m^2]
Arbejdets størrelse [m^2]	Scope of the work [m^2]
nyere	newer
ældre	older

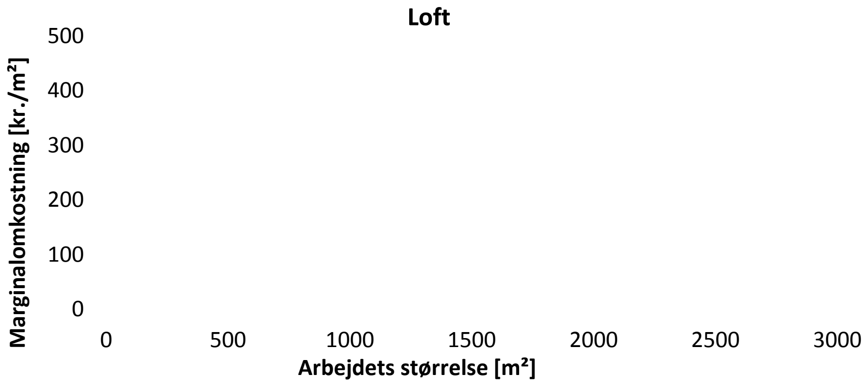

Figure 9. Marginal cost of post-installation insulation of accessible loft spaces.

Danish	English
Loft	Lofts
Marginalomkostning [kr./m^2]	Marginal cost [DKK/m^2]
Arbejdets størrelse [m^2]	Scope of the work [m^2]

In order to determine the cost of renovating buildings' roofs, it is important to know the distribution of roofing materials and thus the indirect lifetime and replacement rate of the roofs.

The price of post-installation insulation of roofs is the same for most roof types, since it is only the cost of post-installation insulation that is included in the calculation. Roofs have therefore been divided up into three price groups, namely flat roofs, slanted roofs and thatched roofs.

The extent to which the price depends on the scope of the work (the shape of the curves in figure 8 and figure 9) is assumed to be the same for the more stringent levels required as for post-installation insulation meeting the BR10 requirement. On the other hand, the price of a given scope determines the position on the curves. table 5 shows the price per m² roof/loft for post-installation insulation to the BR10 requirement and increasing the stringency of the requirement to a U value of 0.12 W/m²K or 0.10 W/m²K respectively.

Table 5. Price per m² of post-installation insulation of roofs/lofts for work on 100 m² at different required levels. The 'more stringent' level refers to scenarios B1-B3, B9-B10 and C1. The 'super stringent' level refers to scenarios B4-B5 and B8.

	BR10 (0.15 W/m²K) <	More stringent (0.12 W/m²K)	Super stringent (0.10 W/m²K)
Lofts	418	523	575
Slanted roofs, older	412	620	682
Slanted roofs, newer	459	641	705
Thatched roofs	408	630	700
Flat roofs	751	850	935

External walls

There is a great difference in the marginal cost of post-installation insulation of various types of external wall. The highest cost is for the post-installation insulation of external walls of bare tile and external walls of various types of concrete, with costs ranging from DKK 2 700 to DKK 1 700 per m², depending on the scope of the work. The costs associated with the post-installation insulation of light facades and the injection of insulation materials into uninsulated cavity walls is of the same order of magnitude, namely DKK 200-400 per m². Figure 10 shows the marginal cost depending on the scope of the work.

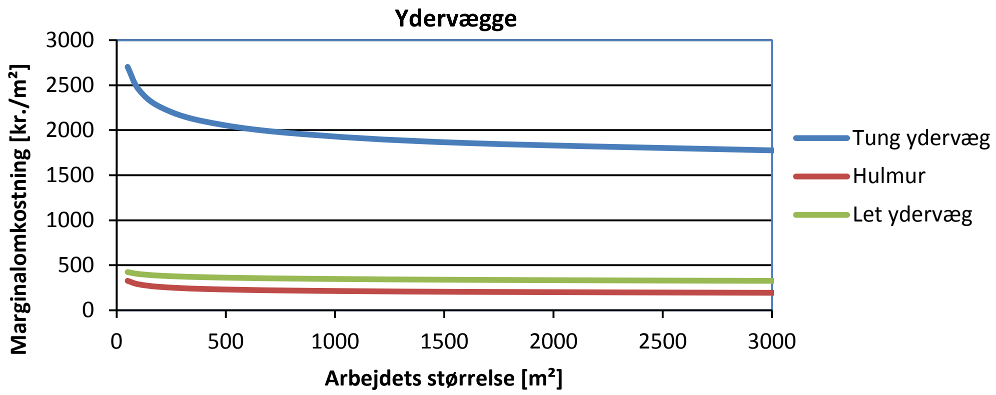

Figure 10. The marginal cost of post-installation insulation of external walls, corresponding to the insulation level specified in table 1.

Danish	English
Ydervægge	External walls
Marginalomkostning [kr./m²]	Marginal cost [DKK/m²]
Arbejdets størrelse [m²]	Scope of the work [m²]
Tung ydervæg	Heavy external wall
Hulmur	Cavity wall
Let ydervæg	Light external wall

Just as for roofs, the price is assumed to depend on the scope of the work to the same extent in the case of more stringent requirements as for the BR10 requirements. The increased stringency levels represent U values of 0.15 and 0.12 W/m²K respectively.

The reason for the large jump (table 6) in the price of post-installation insulation of cavity walls between the BR10 level and the increased stringency levels is due to the fact that the BR10 requirements only include the post-installation insulation of uninsulated cavity walls. If a cavity wall needs to be insulated further, it will require external post-installation insulation, which has approximately the same price as the external post-installation insulation of heavy external walls in order to achieve a given U value.

Table 6. Price per m² of post-installation insulation of external walls for work on 100 m² at different required levels. The 'more stringent' level refers to scenarios B1-B3, B9-B10 and C1. The 'super stringent' level refers to scenarios B4-B5 and B8.

	BR10 (0.20 W/m²K)	More stringent (0.15 W/m²K)	Super stringent (0.12 W/m²K)
Cavity wall	289	2 742	3 017
Heavy external wall	2 454	2 800	3 080
Light external wall	403	540	594

Floors

Figure 11 shows the marginal cost of post-installation insulation of floors adjacent to cellars and available ventilation spaces, depending on the scope of the work. The price includes the laying of battens and insulation slabs.

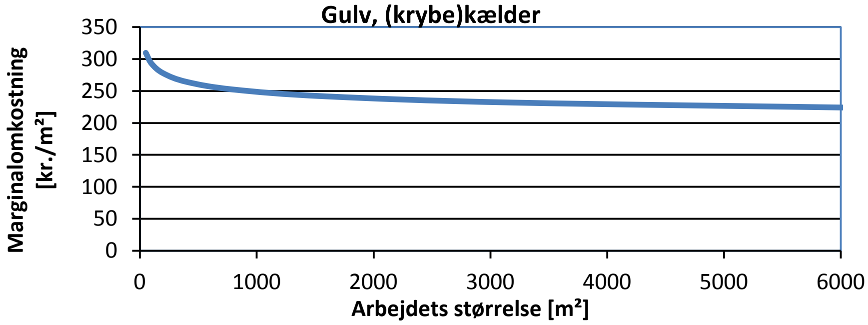

Figure 11. Total costs associated with the insulation of floors adjacent to cellars or accessible ventilation spaces, corresponding to the insulation level specified in table 1.

Danish	English
Gulv, (krybe)kælder	Floors, cellars and ventilation spaces
Marginalomkostning [kr./m²]	Marginal cost [DKK/m²]
Arbejdets størrelse [m²]	Scope of the work [m²]

Windows

The replacement of windows will not be calculated as being dependent on the scope of the work, since it only involves marginal expenditure on materials. The replacement of windows therefore only depends on the energy quality that the new windows must have. In relation to the prices used for the preparation of 'Energy needs of Danish buildings in 2050' [14] and 'Heat savings during ongoing renovations of buildings until 2050' [15] the additional cost of replacing windows of different energy standards was updated on the basis of available prices in December 2013 (please see table 7).

The financial calculations for the replacement of windows assume the same price for the whole period. With regard to the previous price trend for energy-efficient windows in Denmark, this is a very conservative consideration, since a marked reduction in price may be expected by 2050.

Recent technical developments have now made it possible to market windows with a positive thermal balance of up to +24 kWh/m² per annum. There are currently three window manufacturers with a total of six product ranges that have a thermal balance better than +15 kWh/m² per annum (referred to below as A+ windows).

C-rated windows are usually found in the form of traditional frame solutions combined with two energy-efficient panes of glass. Most B-rated windows have three energy-efficient panes of glass. In A-rated windows there is usually either an improved frame solution or three optimised energy-efficient panes of glass. In A+ windows there is usually both an improved frame solution and three optimised energy-efficient panes of glass.

There is not currently any real price structure for A+ windows in the market. Technical initiatives are usually the same in terms of the products as a whole, and for switching from B to A windows and from A to A+ windows. The sequence of initiatives also only depends on the specific choices made by the manufacturer in question. On the basis of these considerations, it is appropriate to assume that the additional cost of switching from A to A+ windows will only be marginally higher than that of switching from B to A windows. It is therefore assumed below that the additional cost of an A+ window as opposed to an A window, at the current price level, will be approximately DKK 400/m², excluding VAT.

Table 7. Current and future additional cost of using windows with improved energy efficiency.

Improvement	Current additional cost DKK/m² excluding VAT	Future additional cost DKK/m² excluding VAT
C → B	120	120
B → A	340	120
A → A+	400	120

Automation and improved efficiency

The installation of better automation and general improvements to the efficiency of building installations covers a very large number of very different initiatives with very different prices. The calculation method relates to the building stock as a whole, and it is therefore assumed that these improvements cost on average DKK 20/m² of heated floor area in the relevant buildings.

At present, there is generally a rapid trend for sensors, actuators and controls that make it cheaper and easier to monitor and control technical installations in buildings. For example, we are constantly seeing more manufacturers working on the development of smartphone applications that make it possible to control various facilities within a building. These include everything from adjusting the temperature, ventilation and solar radiation to switching off individual electrical sockets. There is therefore no doubt that it will be cheaper to control these systems by 2050, by which time we will also see systems that do not exist now. It is not, however, possible at present to guess the future price of facilities for the smart control of a building's energy consumption.

Mechanical ventilation with heat recovery

Mechanical ventilation with heat recovery is primarily assumed to be installed in buildings with slanted roofs and in conjunction with roof renovations so that there is unimpeded access to the roof space.

There is great uncertainty associated with the cost of installing mechanical ventilation in existing buildings, since there are a number of technical and space-related conditions that make it impossible to estimate this on the basis of the general typology of the building. The installation cost, particularly in single-family dwellings, also depends to a very great extent on the size of the house in which the facility is to be installed, since a large proportion of the cost consists of central aggregates that must be in place irrespective of the size of the house.

The cost will also vary depending on the type of building in which the facility is to be installed, and thus the type of facility that will usually be installed. For example, office buildings usually have complex ventilation facilities with variable volumetric flows, as opposed to homes, which usually have simpler facilities.

Figure 12 shows the prices used for the installation of balanced mechanical ventilation in various types and sizes of building.

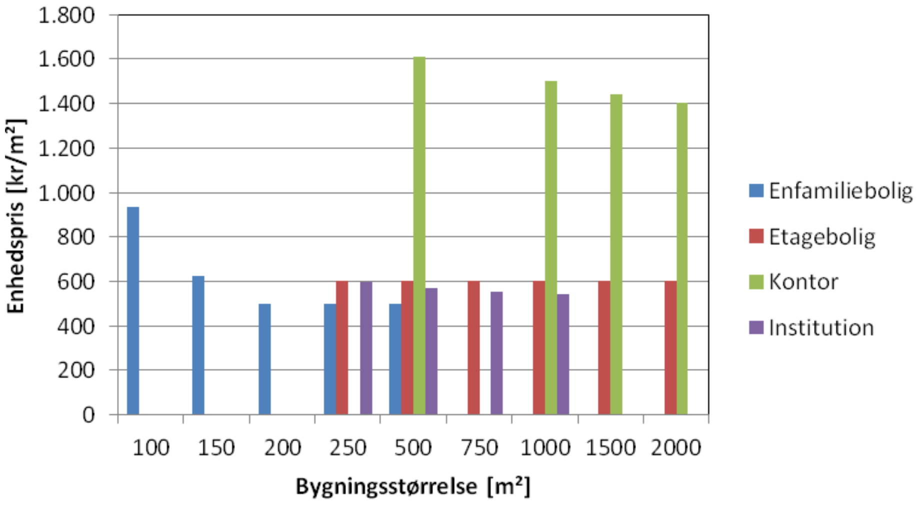

Figure 12 Examples of unit prices used for the installation of balanced mechanical ventilation with heat recovery, depending on the size and type of building.

Danish	English
Enhedspris [kr/m^2]	Unit price [DKK/m^2]
Bygningsstørrelse [m^2]	Size of the building [m^2]
Enfamiliebolig	Single-family dwelling
Etagebolig	Flat
Kontor	Office

The background report for the Energy Renovation Network to use in its work estimates the potential technical improvement of various solutions for energy upgrades to existing buildings [11]. Among other things, it points out that mechanical ventilation systems with heat recovery will presumably achieve lower electricity consumption by 2020, while the degree of recovery for the aggregates remains the same or improves slightly. For the present purpose, single-family dwellings are assumed to have 90 % efficient heat recovery with specific energy consumption of 0.6 kJ/m^3 for air transport. Flats are assumed to have 85 % efficient heat recovery and specific energy consumption of 0.8 kJ/m^3 for air transport. It is hardly likely that these improvements will have any appreciable influence on the total cost of ventilation facilities. Particularly if the Building Regulations impose more stringent requirements for these values, the same trend may be expected for the sub-components of ventilation facilities as for windows, in other words a falling or stagnating price per m^2 together with rising performance.

Extent of implementation of the requirements of the Building Regulations

As part of a subsidiary project connected to the preparation of background materials for the Energy Renovation Network, a qualitative analysis was performed on whether the post-installation requirements of the Building Regulations, as described earlier, are implemented during general renovations [4].

The primary focus of the analysis was on whether the requirements of the Building Regulations are complied with in connection with roof renovations on single-family dwellings and communal buildings. The reasons for these two focal areas are firstly that there is expected to be a risk of the rules not being complied with to a certain extent in the case of the owners of single-family dwellings, and secondly that there is a need to examine whether the owners of public buildings are complying with the rules.

It is not possible on the basis of the analysis that was performed to identify clearly the proportion of single-family dwellings that will not implement the required post-installation insulation in conjunction with roof renovations. This does, however, suggest that the required post-installation insulation will not be implemented in 10-20 % of the roof renovations that are carried out. The reasons cited by contractors for this non-compliance with the rules include profitability, technical options, space, and direct requests from the building owners, which is the least common reason.

Just as is the case for single-family dwellings, it is not possible to identify the proportion of communal buildings that will not implement the required post-installation insulation in conjunction with roof renovations. Unlike single-family dwellings, it is alleged for communal buildings that the reason for a lack of post-installation insulation only needs to appear in a profitability assessment. The impact of post-installation insulation work carried out previously will often have moved the building in question some way along the path towards the current energy requirements, and the heat saving achieved through a further increase in the insulation thickness will therefore not be profitable.

The analyses of the savings potential in the business-as-usual scenarios assume a compliance rate of 80 % for single-family dwellings. In other words, the roof area renovated each year is reduced accordingly. This means that 80 % of the renovated buildings in which post-installation insulation could fall under the category of ‘measures that can often be implemented profitably’ will be insulated following their installation. It is assumed that, owing to a lack of awareness and on the basis of the qualitative analysis, 80 % of all other building types and forms of ownership will have post-installation insulation fitted in conjunction with roof renovations.

Reduced savings in practice

The saving from the implementation of an energy-saving initiative is based on a normative calculation with standard assumptions. Even if energy renovations have already been on the agenda in Denmark for several years, there is still a general lack of awareness and experience of normative savings in practice. Demonstration projects falling under the common designation of Energy Parcel [6] have shown that the real saving is often somewhat lower than the theoretical calculated saving. This is partly explained by a higher mean room temperature following energy renovations, and partly by changes in user behaviour. For example, it could involve large, older houses in which part of the house was ‘shut down’ during the winter months prior to the renovation, or small houses with high levels of heat consumption, the occupants of which have maintained a low indoor temperature and/or lit many fires in order to keep the heating bill down.

This fact has been considered to a limited extent in the calculation by maintaining the number of degree-days equivalent to an assumption that there is a slightly higher indoor temperature over a shorter fire season.

Calculation model

The underlying calculation model has been generated using data from the Buildings and Homes Register (BBR) [2] and statistical data from the Energy-Labelling Scheme (EMO) [5] concerning the insulation standard of buildings and the area of building components per unit area (heated floor area).

A model of unit consumption [kWh/m²] has been created for each type of building use (please see the distribution in the BBR) and in nine typical construction periods. The model includes heat loss through the building envelope, through ventilation, and through consumption of domestic hot water. It also includes contributions to the heating of the buildings in question, in the form of heat released by people and by electrical installations, and solar radiation through the windows of the buildings in question. A degree-day method is used to estimate heat consumption in the current building stock and the potential heat savings.

The same model is also used to estimate the potential for heat savings, since improved insulation capacity is constantly being implemented as some of the buildings undergo renovations. The model may also include the impact of installing ventilation with heat recovery.

The calculation model that has been generated uses a certain distribution of the total building stock (please see the two tables below), in other words a combination of construction period and building use. Table 9 shows the nine construction periods that are characterised either by the typical construction style (older periods) or increased stringency in the Building Regulations (newer periods). Table 8 shows the distribution of the building stock used according to the use code; please see the BBR for the categories included in the analyses.

Table 9 Construction periods used.

Number	Period
p1	Before 1890
p2	1890 - 1930
p3	1931 - 1950
p4	1951 - 1960
p5	1961 - 1972
p6	1973 - 1978
p7	1979 - 1998
p8	1999 - 2006
p9	2007 - 2012

Table 8 Use codes; please see BBR

Code	Description
110	Cottage
120	Single-family dwelling
130	Terraced/link-detached house
140	Flat
150	Hall of residence
160	Residential institution
190	Other year-round accommodation
320	Office/commercial
330	Hotel or service building
390	Other commercial/service
410	Cultural building
420	Education
430	Hospital
440	Daycare institution
490	Other institution
510	Summer house
520	Holiday building
530	Sports facility
590	Other leisure building

Energy calculations

Energy consumption is calculated as net energy consumed for heating, ventilation and domestic hot water plus solar radiation through the windows of the building and heat generated by people and electrical equipment (including lighting).

Building model

An area-weighted U value for each building class and age group is calculated on the basis of data from the EMO. Areas for roofs, floors, external walls and windows in each building type and age group have also been extracted. The heat loss through the building envelope has then been calculated based on the number of degree-days (GD) as:

$$Q = GD \times \sum \overline{U} \times A$$

In addition to the area-weighted mean values for building components in different building types and construction periods, a distribution curve has also been established for the U values for each building type and age group. The distribution curves have been created on the basis of data from the energy-labelling scheme and are therefore a snapshot of the insulation standard of the existing building stock. It is possible to use these distribution curves to find the proportion of the total area of a building component in each building category that has a U value so high that it could be assumed to be financially profitable to carry out an energy upgrade.

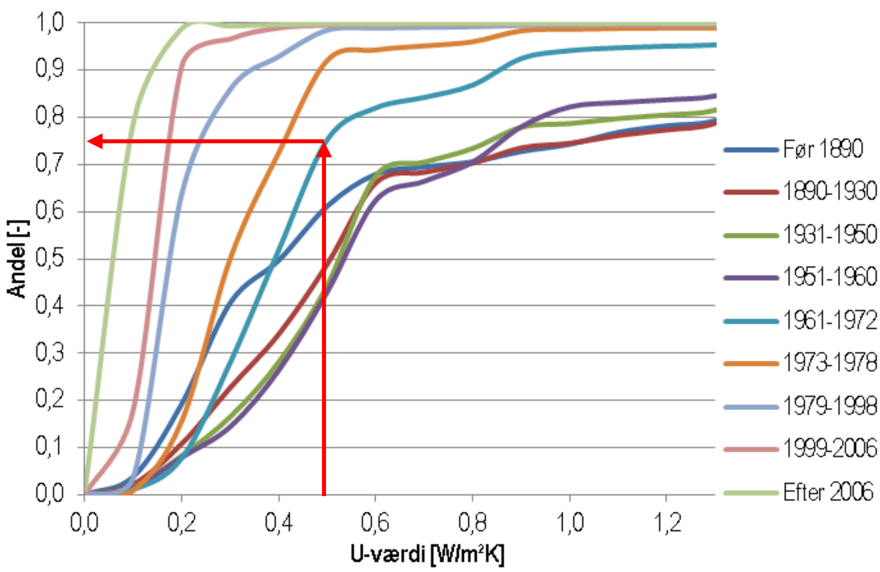

Figure 13. Example (external walls of single-family dwellings) of distribution curve for U values. It is possible to find the proportion of the total external-wall area that lies above a given value. For example, 25 % of external walls built during the 1961-1972 period have a U value in excess of 0.5 W/m²K, and it is usually assumed to be financially profitable to carry out post-installation insulation in conjunction with planned renovation work.

Danish	English
Andel [-]	Proportion [-]
U-værdi [W/m^{2}K]	U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006

The mean U value for the building type and period in question, calculated on the basis of the records for the EMO scheme, is used to calculate the current heating need. The energy need in 2050 is calculated by weighing up the U values of the renovated and non-renovated structures. The proportion of structures that are assumed to be renovated by 2050 is determined by three reduction factors, namely relating to profitability, lifetime, and compliance with the component requirements. Profitability (please see figure 13) is determined according to the proportion (recorded under the EMO scheme) of structures that have a U value in excess of the threshold beyond which post-installation insulation is assumed to be profitable; please see Annex 6 to BR10. The proportion of building components renovated on the basis of age is determined by information from the BBR concerning materials and the year of construction. table 10 shows an example estimate for the proportion of single-family dwellings assumed to undergo post-installation insulation of roofs by 2050 on the basis of the three cut-off criteria.

Table 10. Estimated proportion of roof area of single-family dwellings undergoing post-installation insulation (example), with reduction based on profitability (only post-installation insulation of structures with a U value in excess of 0.2 W/m²K), lifetime, and compliance with the Building Regulations. The total area-weighted roof area that will undergo post-installation insulation by 2050 in scenario A0 is 20.5 %.

Roofs (0.2)	Before 1890	1890 -1930	1931 -1950	1950 -1960	1961 -1972	1973 -1978	1979 -1998	1999 -2006	After 2006
Profitable	40.4 %	47.1 %	46.8 %	43.2 %	34.7 %	26.6 %	3.6 %	0.4 %	0.2 %
Lifetime	66.5 %	83.5 %	84.2 %	83.3 %	78.7 %	82.5 %	84.2 %	84.3 %	82.6 %
Compliance	80 %	80 %	80 %	80 %	80 %	80 %	80 %	80 %	80 %
Insulated after installation	21.5 %	31.5 %	31.5 %	28.8 %	21.8 %	17.5 %	2.4 %	0.2 %	0.1 %

Heat consumption for ventilation is calculated based on an assumption concerning the ventilation rate (q) and indoor temperature of the building types and age groups in question, and on the mean degree of heat recovery for the proportion of buildings that have balanced mechanical ventilation with heat recovery. Heat consumption for ventilation in an average building is calculated as:

$$Q_{vent} = 1.21 \times GD \times \bar{A} \times q \times \left(Z_{nv} + Z_{mequ} \times \left(1 - \varepsilon_{mequ}\right)\right)$$

Z states the proportion of the area of a building and age group that has natural or mechanical ventilation.

Energy consumption for domestic hot water is calculated as a fixed amount of water consumption, depending on the building type, that is heated at 45 °C from 10 °C to 55 °C as:

$$Q_{VBV} = \bar{A} \times q_{VBV} \times C_p \times 45$$

On average, windows are assumed to be positioned precisely in accordance with the distribution used to calculate the energy grant (E_{ref}) through a reference window, please see the energy-labelling scheme for windows. The heat grant through the windows of the average building may thus be calculated as:

$$Q_{windows} = \sum E_{ref} \times \overline{A_{win}}$$

The heat generated by people and electrical equipment found in buildings is also determined by calculating the energy performance of a building in conjunction with construction administration and energy labelling; please see Energy needs of buildings [1].

Financial calculations

The financial costs of the energy-saving initiatives in terms of current prices are based on prices taken from the online edition of the V&S price catalogue for 2012 [12].

Since the initiatives are carried out during other planned renovations of the same building component, only the price of the energy-saving initiative itself has been included. Accordingly, only the price of post-installation insulation work has been included with regard to the replacement of roof cladding, for example. As far as roofs are concerned, for example, this means the removal of old insulation, the supply and assembly of battens and insulation with cross-insulation, the raising of trusses, and the laying of new trestles.

The marginal cost of upgrading windows is set at DKK 0 per m^2 for the replacement of windows that meet the current minimum requirements of the Building Regulations, i.e. C-rated windows. This means that a cost will only be incurred for window renovations after 2015 where the requirement is made more stringent for B-rated windows and in conjunction with scenarios that analyse the more stringent requirements in conjunction with the replacement of windows. The calculation of the total cost includes the difference in price between a C-rated window and the price of the various windows that are better in terms of their energy performance.

All of the costs, other than those incurred for the replacement of windows, will depend on the scope of the work. The impact of this has been included by using the price that applies to the mean building size in each category (use and construction period).

Two prices have been calculated. One is the price based on the V&S price catalogue, and one is the price that takes account of the rationalisation of work processes, new technologies, etc., as described on page 18.

The financial calculation for energy improvements to the building stock is based on a calculation for each type of structure that is assumed to be upgraded. The proportion of structures that will be upgraded is determined by the threshold value (U value) of the structures in question. Only those structures that have a U value in excess of the threshold value are included in the calculation of energy savings and the associated finances (please see the section on the Building model on page 27), since it is not assumed to be financially profitable to carry out post-installation insulation of structures that already had a U value below the threshold. In addition to this, the lifetime of the various construction materials is included as the proportion of the total area of a structure using a given construction material that will be renovated by 2050.

$$E = A \times F_{U\ threshold} \times F_{lifetime} \times F_{implementation} \times e_{component}$$

where:

- $F_{U\ threshold}$ is the proportionate area of the building component that has a U value in excess of the threshold value. It is assumed that it will not be immediately profitable to carry out post-installation insulation of structures in excess of the threshold value.
- $F_{lifetime}$ is the proportion of areas renovated by 2050.
- $F_{implementation}$ is the proportion of renovation tasks complying with the component requirements in the Building Regulations.
- $e_{component}$ is the marginal cost per m² of the component (roof, external wall, floor and window) or per building (ventilation). The costs calculated per building are divided by $\bar{A}$.

Where the total finances for all upgrades carried out by 2050 have been determined, it is possible to distribute the expenditure across the years in question on the basis of the renovation activity determined on the basis of the estimated lifetime and year of construction of the structures in question.

Heat-saving scenarios

Scenarios designated as A show various assumptions concerning the component requirements contained in the Building Regulations 2010 in connection with the replacement and renovation of building components and various speeds for phasing-in these requirements of greater stringency. Scenarios designated as B include analyses of the impact of various component requirements of greater stringency in the Building Regulations. Scenarios designated as C include analyses of various options, other than increasing the stringency of the component requirements, for achieving significant additional heat savings in the existing building stock by 2050.

A model has essentially been generated for calculating the heat consumption of the existing building stock on the basis of reports submitted under the energy-labelling scheme and extrapolation in relation to areas listed in the BBR for various building types and construction periods. Table 11 shows the calculated unit consumption of various building types and construction periods for the purpose of comparison with the various scenarios.

Table 11. Calculated current unit consumption of the building types and construction periods analysed; please see the records of structures' current thermal properties in conjunction with energy labelling.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	184.3	171.4	161.8	151.2	136.2	116.9	100.3	81.0	66.6
Single-family dwelling	170.3	164.7	164.1	154.9	134.3	119.8	105.4	83.9	67.3
Terraced/link-detached house	158.2	157.7	149.3	142.8	119.9	112.6	96.8	81.5	66.4
Flat	151.1	153.9	157.0	148.0	132.3	121.0	108.5	84.0	60.7
Hall of residence	137.9	149.2	136.4	145.7	130.6	139.1	131.7	84.0	58.2
Residential institution	164.1	161.9	152.3	140.2	143.2	136.9	116.0	94.1	63.3
Other year-round home	161.1	165.7	158.4	161.4	135.8	132.7	101.0	80.4	66.6
Office/commercial	129.8	125.2	129.0	126.7	117.5	120.0	103.3	89.6	82.8
Hotel or service building	172.0	166.5	152.4	160.9	157.2	172.0	141.8	122.6	121.1
Other commercial/service	82.7	119.0	123.6	107.4	125.7	139.9	116.6	102.7	96.0
Cultural building	166.0	156.1	156.5	139.2	125.8	118.4	131.2	105.1	96.6
Education	126.2	136.3	141.0	133.8	135.1	145.6	115.1	100.0	86.2
Hospital	195.3	178.4	173.2	177.3	153.8	156.5	149.6	138.6	129.7
Daycare institution	170.7	181.7	173.8	171.6	172.8	166.1	143.5	133.9	115.9
Other institution	177.9	175.8	178.2	201.7	179.1	169.1	139.4	135.3	117.6
Summer house	205.8	162.5	150.0	176.7	154.6	126.6	134.8	90.8	73.1
Holiday building	139.6	150.5	172.4	112.1	137.9	122.1	125.4	68.9	35.9
Sports facility	198.1	206.8	187.8	173.4	165.3	163.1	155.0	138.3	119.3
Other leisure building	163.4	132.0	149.7	154.7	129.8	129.0	115.0	98.6	76.8

1) The calculated unit consumption of buildings intended for other commerce and service and built before 1890 is unrealistically low. There is great uncertainty associated with the data, since there are only very few buildings from this period in the EMO scheme database. There are very few buildings recorded in the BBR for this period, and the uncertainty relating to this period will therefore only have a marginal bearing on the overall results.

Where the unit consumption is known, it is possible to estimate the heat consumption of the average building on the basis of its mean area (table 12).

Table 12. Mean building size (heated area) of the building categories used; please see information from the BBR.

Mean size m²	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	207	191	185	181	191	218	212	217	240
Single-family dwelling	164	164	151	137	150	159	150	162	171
Terraced/link-detached house	135	140	201	204	202	307	289	270	200
Flat	960	1 137	1 581	2 352	3 624	3 989	1 590	1 700	1 873
Hall of residence	1 448	1 013	1 508	1 724	3 613	1 509	910	1 314	1 907
Residential institution	1 117	1 037	1 375	1 958	1 920	2 369	1 115	1 205	1 497
Other year-round home	236	265	333	364	778	582	714	357	702
Office/commercial	1 258	1 441	1 819	1 895	2 625	2 997	3 232	4 714	2 836
Hotel or service building	752	1 198	1 274	2 563	1 275	1 140	1 223	2 971	1 643
Other commercial/service	1 220	393	1 043	857	1 433	829	762	2 553	1 735
Cultural building	584	808	827	905	1 269	2 069	875	873	863
Education	1 704	1 999	2 303	2 726	3 173	3 115	1 974	1 657	2 087
Hospital	1 589	2 781	2 811	2 684	4 155	3 457	6 257	3 469	2 486
Daycare institution	560	482	540	554	522	573	548	551	691
Other institution	1 526	1 038	1 045	914	1 201	1 130	983	861	1 150
Summer house	103	159	165	144	104	380	109	110	111
Holiday building	517	612	439	1 474	560	1 622	981	688	500
Sports facility	459	1 064	657	1 088	2 313	2 177	1 380	1 756	1 854
Other leisure building	338	566	426	344	682	1 865	330	321	469

After generating the energy model for the building stock, as it appears in relation to the records under the EMO scheme, it is possible to create a heat balance for the various building types. Figure 14 to figure 16 show examples of the heat balance for selected building types.

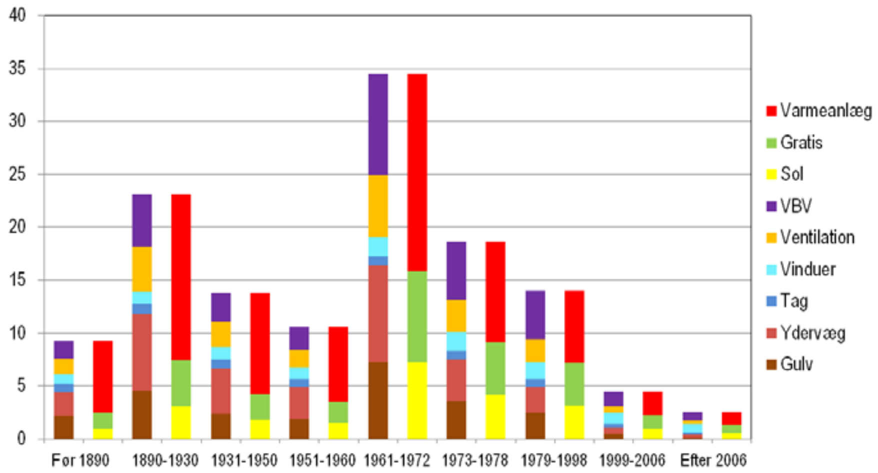

Figure 14. Heat balance (PJ/year) for all single-family dwellings in Denmark in relation to cords under the EMO scheme. (VBV = domestic hot water)

Danish	English
Før 1890	Before 1890
Efter 2006	After 2006
Varmeanlæg	Heat installation
Gratis	Free of charge
Sol	Solar
VBV	VBV (domestic hot water)
Vinduer	Windows
Tag	Roofs
Ydervæg	External walls
Gulv	Floors

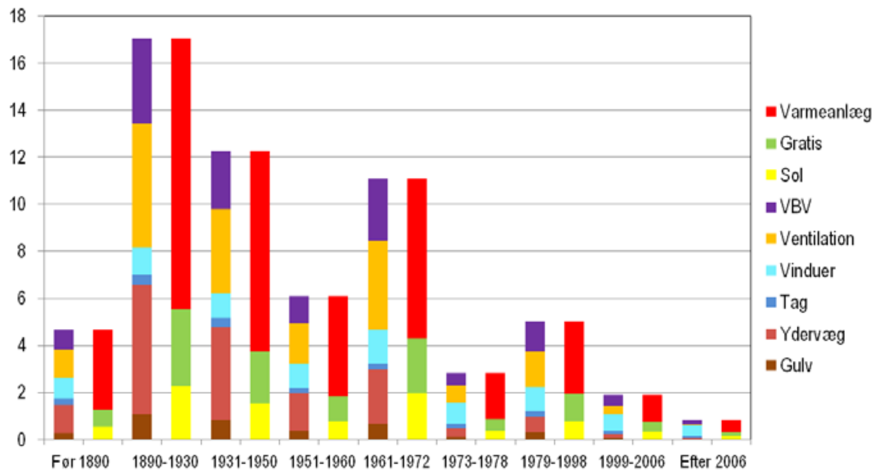

Figure 15. Heat balance (PJ/year) for all flats in Denmark in relation to cords under the EMO scheme.

Danish	English
Før 1890	Before 1890
Efter 2006	After 2006
Varmeanlæg	Heat installation
Gratis	Free of charge
Sol	Solar
VBV	VBV (domestic hot water)
Vinduer	Windows
Tag	Roofs
Ydervæg	External walls
Gulv	Floors

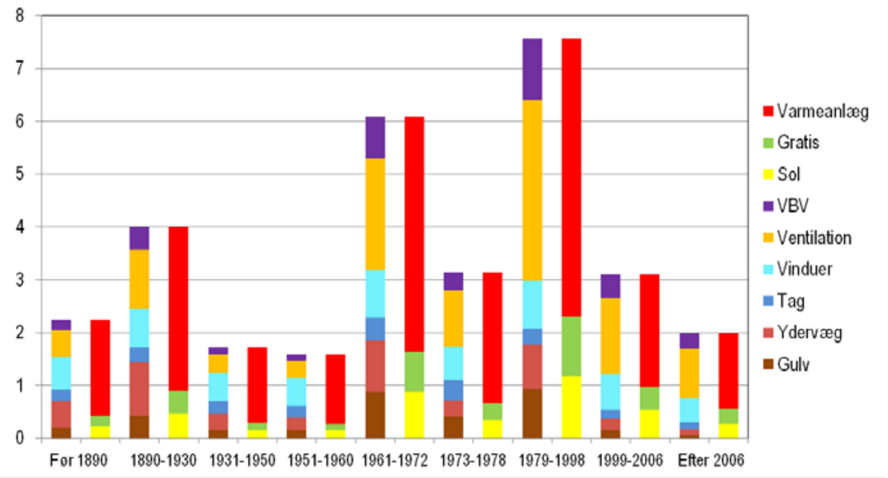

Figure 16. Heat balance (PJ/year) for all commercial and service buildings in Denmark in relation to cords under the EMO scheme.

Danish	English
Før 1890	Before 1890
Efter 2006	After 2006
Varmeanlæg	Heat installation
Gratis	Free of charge
Sol	Solar
VBV	VBV (domestic hot water)
Vinduer	Windows
Tag	Roofs
Ydervæg	External walls
Gulv	Floors

A scenarios - Current component requirements

The A scenarios include analyses of the impact of the current requirements on heat consumption in the existing building stock in conjunction with the renovation and replacement of building components as specified in BR10, hereafter referred to as the 'business-as-usual' scenario. Scenario A0 therefore shows the impact if no adjustments are made to the requirements or the degree of compliance with the requirements. Scenario A1 analyses the consequences of the requirements being complied with in full (100 %), in contrast with the current situation where a small proportion of buildings do not comply with the requirements for financial, technical or architectonic reasons meaning that the requirements need not be complied with, as well as a lack of awareness of the requirements on the part of the building owners. Scenario A2 shows the significance of 90 % implementation of the component requirements in BR10. Scenarios A3 and A4 analyse the impact of a longer lifetime for the building components than is calculated in scenario A0, as well as the impact of the requirements if all roofs undergo post-installation insulation by 2050. Scenario A5 analyses the significance of rapidly phasing-in a requirement to replace windows with A-rated windows.

A0 – 'Business as usual'

This scenario is based on the component requirements contained in the Building Regulations 2010 in conjunction with the renovation or replacement of building components. The energy-saving measures are implemented as the building components face renovation or replacement owing to their age, and if the existing insulation level does not meet the requirements of BR10. It is also assumed that 80 % of the relevant roof and external-wall area will undergo post-installation insulation in accordance with the requirements of the Building Regulations[2]. This therefore means that 20 % of the relevant area will not be upgraded as a result of technical, architectonic and/or financial-profitability reservations. This will be the case even if these works may often be assumed to be profitable.

The ongoing replacement or renovation of tiled walls is deemed to be relatively low, owing to their long lifetimes. It is assumed that other reasons, such as the desire for a better indoor climate and lower heating bills, will mean that a small proportion of tiled-wall area will undergo post-installation insulation. This scenario therefore assumes that 0.5 % of the tiled external-wall area will undergo post-installation insulation each year. Owing to the high prevalence of tiled external walls in the existing Danish building stock, this renovated proportion of tiled external walls completely dominates the heat savings for external walls. Light external-wall cladding is replaced in line with ongoing renovations.

For windows, it is assumed that the area that is replaced is upgraded in accordance with the requirements of the Building Regulations, which cover a small proportion of the area that does not meet the requirements, for example because the windows are not replaced but are instead fitted with double glazing or the glass is simply removed, and some windows are replaced with better ones than are required.

For all components other than windows, only that part of the component area (please see figure 13 on page 27 and table 10 on page 28) that has a U value in excess of the threshold value is assumed to have undergone post-installation insulation/replacement. The threshold value is set depending on the post-installation insulation work that is usually regarded as being financially profitable. Building models have been created for all building types on the basis of data from the BBR, including the mean size of the buildings. They show the mean size (heated area) of the individual building categories (age and type).

If developments continue at the current rate, annual heat consumption in 2050 will be 148 978 TJ per annum, or 57 199 TJ per annum (27.7 %) less than in 2011.

[2] The relevant area corresponds to that estimated by the model to be renovated each year on the basis of mean lifetimes. The area for external walls is therefore limited, since approximately 80 % are built using tiles, which have a relatively long lifetime.

Table 13 Calculated unit consumption in 2050 for the building types and construction periods analysed; please see the energy improvements made under scenario A.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	132.4	122.1	113.8	106.2	99.2	86.5	77.4	64.6	57.4
Single-family dwelling	123.3	113.3	111.4	105.0	94.7	87.8	81.0	70.3	58.8
Terraced/link-detached house	113.3	108.5	102.2	97.8	84.6	79.5	74.3	67.3	57.6
Flat	101.9	101.6	103.4	101.3	94.8	88.2	86.3	70.5	48.9
Hall of residence	99.4	104.2	95.7	97.3	97.6	103.2	99.5	72.4	48.9
Residential institution	120.9	118.6	113.3	109.2	113.7	111.6	95.5	79.4	55.8
Other year-round home	108.3	113.0	108.7	112.8	101.8	98.1	73.5	68.3	55.0
Office/commercial	85.6	84.8	86.4	89.6	86.0	93.3	83.3	77.0	75.1
Hotel and service	131.5	127.4	115.1	124.5	124.2	138.2	122.5	111.8	112.1
Other commercial/ service	68.7	95.3	95.2	81.5	95.8	105.2	93.9	86.7	83.8
Cultural building	117.0	109.7	112.6	102.8	95.2	93.6	108.1	92.0	89.1
Education	87.3	94.4	102.4	96.3	101.5	117.9	95.0	86.7	78.6
Hospital	140.9	134.8	132.3	132.2	124.4	133.7	132.5	128.2	122.5
Daycare institution	124.0	135.1	130.2	133.5	134.3	133.4	121.0	118.6	110.7
Other institution	127.2	129.7	133.7	151.7	139.4	133.9	119.0	120.6	108.4
Summer house	118.3	99.9	92.8	92.7	94.3	79.0	79.5	62.7	57.7
Holiday building	97.0	109.2	122.0	81.1	90.7	80.6	82.7	56.4	29.4
Sports facility	150.6	157.6	143.1	139.3	141.2	144.6	140.6	126.5	114.6
Other leisure building	118.9	86.9	99.2	99.4	94.1	89.1	85.9	81.2	68.2

A1 – Full compliance with the Building Regulations

Scenario A1 estimates the impact of 100 % implementation (i.e. the same as scenario A0 but with full implementation on all of the relevant area) of the energy requirements in BR10 in conjunction with the renovation or replacement of building components. In other words, the question of whether post-installation insulation is profitable or possible in terms of construction or moisture technology is not taken into account. Post-installation insulation will still, however, only be carried out on the area that has a U value in excess of the threshold for structures in which post-installation insulation is assumed to be 'often profitable'; please see Annex 6 to the Building Regulations 2010.

If full compliance with the component requirements specified in the Building Regulations 2010 is assumed, annual heat consumption in 2050 will be 141 446 TJ per annum, corresponding to a reduction of 31.4 %. This is 7 532 TJ lower than if the trend continued as it has to date.

Table 14 Unit consumption in 2050 with full compliance with the component requirements in the Building Regulations 2010 for roofs, external walls and windows.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	123.6	113.9	106.0	99.0	94.6	83.5	76.0	63.3	57.4
Single-family dwelling	115.7	105.0	102.8	97.4	90.1	84.9	79.6	69.6	58.9
Terraced/link-detached house	106.4	100.4	94.6	91.2	80.7	76.8	73.2	66.7	57.4
Flat	94.2	93.2	94.4	94.5	90.7	85.1	85.0	69.8	48.5
Hall of residence	93.8	97.2	89.3	90.2	94.4	99.1	96.1	72.1	48.6
Residential institution	114.6	111.5	107.6	104.9	110.7	109.2	94.2	78.8	55.7
Other year-round home	99.3	104.2	100.7	104.6	98.5	94.7	70.7	68.2	54.9
Office/commercial	78.8	78.7	80.0	84.4	82.3	90.2	82.1	76.4	75.0
Hotel and service	125.1	121.5	109.7	118.9	120.2	134.5	121.3	111.4	111.9
Other commercial/ service	67.8	93.2	93.4	79.7	93.4	101.5	91.8	84.7	82.5
Cultural building	108.9	101.9	105.1	98.0	91.7	91.8	106.7	91.4	89.1
Education	81.2	87.9	97.0	91.2	97.7	114.9	93.8	86.1	78.6
Hospital	131.0	127.6	125.6	124.2	120.5	130.7	131.3	127.5	122.4
Daycare institution	116.3	127.8	123.3	128.4	130.1	130.2	119.7	118.1	111.1
Other institution	118.6	121.9	126.4	143.7	134.4	129.4	117.7	119.8	108.4
Summer house	102.2	89.3	85.4	78.8	84.9	71.0	73.1	61.0	57.6
Holiday building	90.4	102.9	113.8	76.5	85.0	74.9	77.1	55.9	29.6
Sports facility	142.4	148.8	135.5	134.2	137.5	141.9	139.0	125.4	114.6
Other leisure building	111.6	79.5	90.9	91.1	88.6	85.2	83.7	80.4	68.5

A2 – 90 % post-installation insulation during renovations

This scenario analyses the impact of a special initiative to ensure that building owners are aware of the requirement concerning post-installation insulation in conjunction with the renovation and replacement of building components. It is assumed that 10 % of building components that are renovated will still not undergo post-installation insulation to the requirements laid down in the Building Regulations 2010, but this will only be for financial, technical or architectonic reasons. This scenario therefore lies somewhere between the business-as-usual scenario and the scenario in which there is full compliance with the component requirements laid down in the Building Regulations 2010.

With this scenario, heat consumption in the proportion of the building stock that is analysed will be 145 212 TJ in 2050, corresponding to a reduction in heat consumption of 60 966 TJ (29.6 %) in relation to current consumption, and an additional reduction of 3 766 TJ in relation to the business-as-usual scenario.

This scenario is used as the basis for the B scenarios.

Table 15. Unit consumption in 2050 with 90 % implementation of energy improvements in conjunction with the renovation/replacement of roofs, external walls and windows.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	128.0	118.0	109.9	102.6	96.9	85.0	76.7	64.0	57.4
Single-family dwelling	119.5	109.1	107.1	101.2	92.4	86.4	80.3	70.0	58.8
Terraced/link-detached house	109.8	104.5	98.4	94.5	82.6	78.1	73.7	67.0	57.5
Flat	98.0	97.4	98.9	97.9	92.8	86.7	85.7	70.1	48.7
Hall of residence	96.6	100.7	92.5	93.7	96.0	101.2	97.8	72.2	48.8
Residential institution	117.8	115.1	110.4	107.1	112.2	110.4	94.8	79.1	55.8
Other year-round home	103.8	108.6	104.7	108.7	100.2	96.4	72.1	68.3	54.9
Office/commercial	82.2	81.8	83.2	87.0	84.2	91.8	82.7	76.7	75.0
Hotel and service	128.3	124.4	112.4	121.7	122.2	136.4	121.9	111.6	112.0
Other commercial/ service	68.2	94.2	94.3	80.6	94.6	103.4	92.8	85.7	83.2
Cultural building	112.9	105.8	108.9	100.4	93.5	92.7	107.4	91.7	89.1
Education	84.2	91.2	99.7	93.8	99.6	116.4	94.4	86.4	78.6
Hospital	136.0	131.2	128.9	128.2	122.5	132.2	131.9	127.8	122.5
Daycare institution	120.1	131.5	126.7	131.0	132.2	131.8	120.4	118.4	110.9
Other institution	122.9	125.8	130.1	147.7	136.9	131.7	118.4	120.2	108.4
Summer house	110.2	94.6	89.1	85.7	89.6	75.0	76.3	61.8	57.7
Holiday building	93.7	106.0	117.9	78.8	87.8	77.8	79.9	56.2	29.5
Sports facility	146.5	153.2	139.3	136.8	139.3	143.2	139.8	126.0	114.6
Other leisure building	115.3	83.2	95.0	95.3	91.3	87.1	84.8	80.8	68.4

A3 - Extension of roof lifetimes by 25 %

This scenario shows the net heat saving as for the reference scenario, but extending the lifetime of roof cladding by 25 %.

The extended lifetime of windows has no bearing on the resultant heat saving in 2050, since windows installed in 2020 (B-rated windows) will in any case be assumed to have been replaced by A-rated windows by 2050, owing to their lifetime. Just as with windows, all light external-wall cladding is assumed to have been replaced at least once by 2050 owing to its expected lifetime. The renovation of heavy external walls is completely dominated by the assumed renovation pace of 0.5 % per annum for external walls of this type, and it therefore has no bearing on this scenario. The present scenario therefore only analyses the consequences of a longer roof lifetime.

If it is assumed that the roof lifetime is extended by 25 % in relation to scenario A0, annual heat consumption in 2050 will be calculated as 156 072 TJ per annum in relation to current heat consumption. Heat consumption will therefore increase by 3.4 % in 2050 in comparison with continuation of the current trend, as assumed in the business-as-usual scenario.

Table 16. Unit consumption in 2050 with 25 % longer roof lifetime and also a trend continuing as it has to date with regard to energy improvements in conjunction with the renovation/replacement of roofs, external walls and windows.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	139.4	128.1	119.5	112.6	104.1	90.6	79.5	67.5	62.0
Single-family dwelling	129.8	119.0	117.3	110.5	99.6	91.4	83.2	74.2	63.5
Terraced/link-detached house	117.2	113.7	106.8	103.0	91.2	85.3	76.5	71.0	62.0
Flat	106.1	107.1	108.5	104.3	99.5	92.9	88.3	74.5	53.5
Hall of residence	100.7	105.7	100.7	101.4	103.1	109.5	99.2	77.0	52.4
Residential institution	123.5	121.2	115.3	111.4	118.2	116.6	97.8	83.5	59.8
Other year-round home	116.3	118.2	114.7	121.3	105.3	101.4	74.3	72.7	59.4
Office/commercial	88.4	87.5	90.3	94.6	92.3	99.6	85.9	80.2	77.8
Hotel and service	133.3	130.0	119.6	131.5	131.1	145.7	124.5	114.3	114.4
Other commercial/ service	71.0	99.9	101.5	86.8	104.3	120.3	98.0	93.2	86.4
Cultural building	119.9	113.0	114.6	106.8	101.3	98.4	111.0	94.9	91.8
Education	89.8	97.3	105.6	100.1	108.1	124.3	97.7	90.4	81.5
Hospital	145.5	138.0	135.7	137.1	129.8	141.0	134.8	130.6	125.1
Daycare institution	126.0	137.3	132.2	135.7	140.6	138.9	123.2	122.0	113.4
Other institution	132.5	132.3	137.7	156.9	147.7	142.6	121.1	123.1	111.7
Summer house	137.4	106.4	106.1	98.2	101.5	88.9	84.6	69.6	65.3
Holiday building	101.5	111.6	124.7	83.1	94.4	83.5	85.8	60.5	32.2
Sports facility	152.5	159.7	145.3	141.4	142.8	145.9	142.0	128.9	116.7
Other leisure building	121.4	89.4	101.6	102.4	96.2	92.8	89.2	85.6	71.9

A4 – All roofs insulated following installation by 2050

This scenario shows the net heat saving as per the reference scenario but with compulsory post-installation insulation of the roof area that would not otherwise have been replaced by 2050 during general renovations on the basis of the long lifetime of the roofing materials. The ‘missing’ roof area is assumed to undergo post-installation insulation during the 2040-2050 period and to be equally distributed over that period.

According to an estimate of roof lifetimes, 19 % of the total roof area will not yet have undergone post-installation insulation by 2050 as a result of planned, age-related renovation/replacement. These roofs are all slanted roofs and presumably do not have accessible loft space. The mean residual lifetime of these roofs is approximately ten years (i.e. 20 % of their total mean lifetime), so the additional costs of compulsory post-installation insulation will also be approximately 20 % of the total costs of roof renovation.

An intensive effort concerning the post-installation insulation requirement for all roofs by 2050 will result in annual heat consumption in 2050 of 145 943 TJ per annum (saving of 29.2 %), or 3 035 TJ per annum less than if the trend continues as it has to date.

A5 – Rapid phasing-in of requirement for A-rated windows

In this scenario, the requirements concerning the replacement of windows are assumed to be made more stringent in 2050 so as to meet the current 2020 requirement. In other words, windows that are replaced from 2015 onwards must have an energy rating of A.

Introducing a mandatory requirement for A-rated windows will not have any impact in terms of energy on heat consumption in 2050. This is because the lifetime of the windows means that all A-rated windows installed by 2019 will have been replaced by 2044. Even if the lifetime of the windows is extended to 30 years, accelerating the requirement for A-rated windows will not have any impact on heat consumption in 2050.

B scenarios - More stringent component requirements

In its report [9] and [10], the Energy Renovation Network recommended that the component requirements be made more stringent so as to assess how the target of 50 % energy savings in the existing building stock can be achieved by 2050. The B scenarios therefore include analyses of various draft measures to increase the stringency of the component requirements for individual components, as well as combinations of various measures to increase stringency that could be introduced in the Building Regulations from 2015 onwards. Comparisons of heat consumption in 2050 will still be made, however, with the current standards and with scenario A0, Business as usual.

The starting point for the B scenarios is scenario A2, i.e. 90 % compliance with the BR requirements in conjunction with the renovation/replacement of building components, since it is expected that this will be achieved by means of various campaigns.

Table 17. Overview of various potential requirements that could be made more stringent in the BR from 2015 onwards, as used in the B and C scenarios. The ‘more stringent’ level refers to scenarios B1-B3, B9-B10 and C1. The ‘super stringent’ level refers to scenarios B4-B5 and B8.

Required level: Building component	Current	More stringent	Super stringent
Lofts and roofs, U	0.15 W/m²K	0.12 W/m²K	0.10 W/m²K
External walls, U	0.20 W/m²K	0.15 W/m²K	0.12 W/m²K
Windows, E_{ref}	2015:-17 kWh/m² per ann 2020: 0 kWh/m² per annu	2015:-17 kWh/m² per ann 2020: 0 kWh/m² per annu	2015:-17 kWh/m² per ann 2020: 0 kWh/m² per annu 2025: +15 kWh/m² per an

As a result of the short lifetime of the windows, accelerating the requirement for A-rated windows from 2020 to 2015 will not have any impact on heat consumption in 2050. No separate scenario to assess this factor has therefore been carried out.

B1 - More stringent requirements in conjunction with roof renovations

On the basis of scenario A2 (with regard to the implementation rate and the threshold value for the post-installation insulation of roofs), this scenario estimates the impact of implementing more stringent requirements in conjunction with the replacement of roof cladding. In this scenario, the requirement for the post-installation insulation of roofs/lofts is made more stringent so that the required U value is reduced from 0.15 W/m²K to 0.12 W/m²K, corresponding to a shift from a mean efficient insulation thickness[3] of approximately 300 mm to approximately 400 mm.

The impact of introducing more stringent requirements for roof insulation in conjunction with renovations is relatively limited, since the last cm of insulation provides a relatively small reduction in consumption compared to the first cm. The calculated heat consumption in 2050 if the roof-insulation requirements are made more stringent and if the trend continues as it has to date will be 144 075 TJ per annum (30.1 % reduction in heat consumption in 2050), or a further reduction of 4 903 TJ per annum in relation to the business-as-usual scenario.

Table 18. Calculated unit consumption in 2050 with the introduction of more stringent requirements for the post-installation insulation of roofs, and with other renovations in accordance with scenario A2.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	126.8	117.0	108.9	101.7	96.0	84.2	76.2	63.5	56.9
Single-family dwelling	118.3	108.2	106.2	100.3	91.4	85.5	79.7	69.4	58.3
Terraced/link-detached house	109.0	103.6	97.7	93.7	81.5	77.2	73.2	66.5	57.0
Flat	97.7	97.0	98.5	97.5	92.3	86.2	85.3	69.8	48.4
Hall of residence	96.3	100.3	92.0	93.3	95.3	100.1	97.3	71.8	48.6
Residential institution	117.2	114.5	110.0	106.5	111.2	109.2	94.2	78.5	55.1
Other year-round home	102.6	107.7	103.9	107.6	99.2	95.6	71.6	67.5	54.7
Office/commercial	81.8	81.4	82.7	86.4	83.3	90.8	82.1	76.2	74.5
Hotel and service	127.8	123.9	111.7	121.0	121.0	135.3	121.3	111.3	111.7
Other commercial/service	68.0	93.7	93.7	80.1	93.9	102.1	92.2	85.0	82.7
Cultural building	112.1	105.1	108.1	99.4	92.4	91.9	106.5	91.1	88.3
Education	83.8	90.6	99.1	92.9	98.4	115.1	93.5	85.7	77.9
Hospital	135.4	130.7	128.5	127.6	121.8	131.1	131.2	127.3	121.8
Daycare institution	119.5	130.8	126.1	130.2	130.9	130.5	119.6	117.7	110.1
Other institution	122.3	125.2	129.2	146.6	135.6	130.4	117.8	119.6	107.6
Summer house	108.4	93.4	87.9	84.8	88.4	73.9	75.5	61.1	56.9
Holiday building	92.8	105.2	116.6	78.3	87.0	77.1	79.1	55.6	28.8
Sports facility	145.5	152.4	138.3	135.9	138.1	142.0	138.9	125.3	114.0
Other leisure building	114.3	82.5	94.2	94.3	90.3	86.1	83.9	80.3	67.9

[3] Based on insulation capacity of 0.037 W/mK for the insulation material.

B2 - More stringent requirements in conjunction with replacement of external-wall cladding

On the basis of scenario A2, this scenario estimates the impact of introducing more stringent requirements for the level of post-installation insulation in conjunction with the renovation of external walls and external-wall cladding.

In this scenario, the requirement for the post-installation insulation of external walls is made more stringent so that the required U value is reduced from 0.20 W/m²K to 0.15 W/m²K.

The impact of introducing more stringent requirements for external-wall insulation in conjunction with renovations, as is the case for roof insulation, is relatively limited, since the last cm of insulation provides a relatively small reduction in consumption compared to the first cm. The calculated heat consumption in 2050 if the roof-insulation requirements are made more stringent and if the trend continues as it has to date will be 143 445 TJ per annum (a saving of 30.4 %), or a further reduction of 5 533 TJ per annum in relation to the business-as-usual scenario.

Table 19. Calculated unit consumption in 2050 with the introduction of more stringent requirements for the post-installation insulation of external walls, and with other renovations in accordance with scenario A2.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	127.0	116.9	108.8	101.6	96.0	84.2	75.9	62.9	56.3
Single-family dwelling	118.4	107.9	105.8	100.0	91.4	85.4	79.3	68.7	57.6
Terraced/link-detached house	109.0	103.5	97.4	93.5	81.8	77.2	72.9	66.1	56.5
Flat	97.1	96.5	98.0	97.0	91.9	85.8	84.8	69.3	47.9
Hall of residence	95.9	99.8	91.8	92.9	95.1	100.2	96.8	70.4	47.6
Residential institution	116.9	114.1	109.6	106.3	111.5	109.7	94.1	78.2	54.9
Other year-round home	102.8	107.4	103.6	107.7	99.4	95.5	71.1	65.6	53.1
Office/commercial	81.4	81.0	82.4	86.2	83.4	91.0	81.8	75.8	74.1
Hotel and service	127.4	123.6	111.6	121.1	121.5	135.5	121.0	110.8	111.2
Other commercial/ service	67.8	92.9	93.3	79.3	93.3	102.4	90.8	84.4	81.8
Cultural building	111.9	104.8	107.9	99.6	92.6	91.9	106.3	90.5	87.9
Education	83.5	90.3	98.9	93.0	98.9	115.7	93.6	85.3	77.6
Hospital	134.9	130.4	128.2	127.3	121.6	131.4	131.2	127.0	121.5
Daycare institution	119.1	130.4	125.7	130.0	131.0	130.5	119.1	116.5	109.2
Other institution	121.6	124.7	128.8	146.8	135.9	130.9	117.2	118.7	107.1
Summer house	108.5	92.0	84.7	80.3	84.3	68.2	70.3	56.4	51.8
Holiday building	92.7	104.9	115.6	77.8	86.5	76.6	78.5	53.6	28.7
Sports facility	145.2	152.1	137.7	135.9	138.5	142.4	138.6	124.1	113.2
Other leisure building	114.2	82.1	93.4	93.6	90.1	86.1	82.5	78.0	65.3

B3 – More stringent requirements for roofs and external walls

The combination of scenarios in B1 and B2 shows the impact of introducing more stringent component requirements for roofs and external walls and of accelerating the requirement for A-rated windows (the latter will not have any impact on heat consumption in 2050) in conjunction with the renovation and replacement of the components as they reach the end of their functioning lifetime, and 90 % compliance with the requirements. table 17 gives an overview of the current and more stringent component requirements in this scenario, and table 20 shows the unit consumption of the various building types in 2050.

The calculated heat consumption per annum in 2050 with this scenario is 142 308 TJ per annum, corresponding to an annual saving of 63 869 TJ per annum or 31.0 % in relation to current heat consumption.

Table 20. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of more stringent component requirements in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	125.8	115.9	107.8	100.7	95.0	83.3	75.4	62.4	55.9
Single-family dwelling	117.2	107.0	104.9	99.1	90.4	84.6	78.8	68.2	57.1
Terraced/link-detached house	108.1	102.7	96.7	92.7	80.7	76.3	72.4	65.6	56.0
Flat	96.8	96.1	97.6	96.6	91.4	85.3	84.5	69.0	47.5
Hall of residence	95.6	99.4	91.3	92.5	94.3	99.1	96.3	70.0	47.4
Residential institution	116.3	113.6	109.1	105.8	110.5	108.5	93.5	77.7	54.2
Other year-round home	101.6	106.6	102.8	106.6	98.5	94.8	70.6	64.9	52.9
Office/commercial	81.0	80.5	81.9	85.6	82.6	90.0	81.2	75.3	73.6
Hotel and service	126.9	123.1	110.9	120.4	120.3	134.4	120.4	110.4	110.9
Other commercial/service	67.5	92.3	92.7	78.8	92.6	101.2	90.2	83.7	81.3
Cultural building	111.1	104.1	107.1	98.6	91.6	91.1	105.5	89.9	87.1
Education	83.0	89.8	98.3	92.2	97.7	114.4	92.8	84.6	76.9
Hospital	134.4	129.9	127.7	126.8	121.0	130.3	130.5	126.5	120.9
Daycare institution	118.5	129.7	125.1	129.3	129.7	129.2	118.3	115.7	108.3
Other institution	121.0	124.2	128.0	145.7	134.6	129.6	116.6	118.1	106.3
Summer house	106.7	90.8	83.4	79.3	83.1	67.1	69.4	55.7	51.0
Holiday building	91.8	104.1	114.3	77.3	85.6	75.9	77.7	53.1	28.0
Sports facility	144.2	151.3	136.7	135.0	137.2	141.2	137.7	123.4	112.6
Other leisure building	113.2	81.5	92.6	92.6	89.1	85.1	81.6	77.5	64.8

B4 - Super stringency of requirements in conjunction with roof renovations

This scenario examines the impact of super stringency of the component requirements (please see table 17 on page 39) in conjunction with the replacement and renovation of roofs. The same pace of renovation is also assumed as in scenario A2, i.e. replacement and renovation as the roofs reach the end of their lifetimes, and compliance with the more stringent BR requirements in 90 % of the renovated roof area.

The calculated heat consumption per annum in 2050 with this scenario will be 143 318 TJ per annum, or a reduction of 62 860 TJ per annum (30.5 %) in relation to current heat consumption.

Table 21. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of super-stringent requirements for roofs in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	126.0	116.3	108.3	101.1	95.4	83.7	75.8	63.2	56.6
Single-family dwelling	117.5	107.6	105.6	99.7	90.8	85.0	79.4	69.1	58.0
Terraced/link-detached house	108.4	103.0	97.2	93.1	80.8	76.6	72.9	66.1	56.6
Flat	97.5	96.8	98.3	97.3	92.0	85.8	85.1	69.6	48.2
Hall of residence	96.2	100.0	91.7	93.1	94.8	99.3	97.0	71.5	48.5
Residential institution	116.8	114.1	109.7	106.1	110.5	108.5	93.8	78.1	54.6
Other year-round home	101.8	107.1	103.4	106.8	98.6	95.1	71.3	67.0	54.5
Office/commercial	81.5	81.1	82.4	85.9	82.7	90.1	81.6	75.9	74.1
Hotel and service	127.5	123.5	111.3	120.5	120.3	134.6	120.9	111.1	111.5
Other commercial/ service	67.8	93.3	93.3	79.8	93.4	101.2	91.7	84.6	82.4
Cultural building	111.6	104.7	107.6	98.8	91.7	91.3	106.0	90.8	87.8
Education	83.4	90.3	98.7	92.3	97.7	114.2	93.0	85.3	77.4
Hospital	135.1	130.4	128.2	127.3	121.4	130.4	130.8	127.0	121.4
Daycare institution	119.1	130.3	125.6	129.7	130.0	129.6	119.1	117.2	109.5
Other institution	121.9	124.8	128.7	145.8	134.8	129.5	117.3	119.1	107.1
Summer house	107.2	92.6	87.0	84.2	87.6	73.1	74.9	60.7	56.4
Holiday building	92.2	104.6	115.7	78.0	86.4	76.6	78.6	55.2	28.4
Sports facility	144.9	151.9	137.7	135.3	137.2	141.2	138.3	124.8	113.6
Other leisure building	113.6	82.1	93.7	93.6	89.7	85.4	83.3	79.9	67.6

B5 - Super stringency of requirements in conjunction with external walls

This scenario, like scenario B4, is based on the increased stringency proposed for external walls as specified in table 17 and other developments as in scenario A2. This scenario only examines the impact of introducing super-stringent requirements in conjunction with the renovation and replacement of external walls.

The calculated heat consumption per annum in 2050 with this scenario will be 141 839 TJ per annum, or a reduction of 64 339 TJ per annum (31.2 %) in relation to current heat consumption.

Table 22. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of super-stringent requirements for external walls in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	125.8	115.7	107.6	100.5	94.9	83.2	75.0	62.0	55.4
Single-family dwelling	117.3	106.6	104.3	98.7	90.2	84.4	78.3	67.7	56.6
Terraced/link-detached house	108.0	102.4	96.4	92.5	80.8	76.2	71.9	65.2	55.7
Flat	96.1	95.5	97.0	95.9	91.0	85.0	83.9	68.5	47.1
Hall of residence	95.1	98.8	90.9	91.8	94.1	99.0	95.7	69.4	46.8
Residential institution	115.9	113.1	108.7	105.5	110.7	109.0	93.4	77.4	54.2
Other year-round home	101.6	106.2	102.5	106.7	98.6	94.6	70.3	64.3	52.1
Office/commercial	80.4	80.1	81.6	85.5	82.7	90.4	81.2	75.2	73.6
Hotel and service	126.4	122.7	110.8	120.5	120.7	134.6	120.3	110.1	110.7
Other commercial/ service	67.3	91.8	92.4	78.1	92.3	101.7	89.8	83.7	81.1
Cultural building	110.8	103.8	106.9	98.8	91.9	91.4	105.5	89.7	87.1
Education	82.6	89.4	98.1	92.2	98.2	115.1	93.0	84.5	77.0
Hospital	133.8	129.4	127.4	126.4	120.9	130.7	130.5	126.2	120.8
Daycare institution	118.0	129.3	124.7	129.0	130.0	129.5	118.1	115.4	108.2
Other institution	120.5	123.7	127.9	145.9	135.1	130.1	116.4	117.8	106.3
Summer house	106.7	90.4	83.0	78.2	82.3	65.7	68.1	54.5	49.8
Holiday building	91.6	103.9	114.3	77.1	85.5	75.6	77.6	52.5	28.1
Sports facility	144.0	151.1	136.6	135.0	137.8	141.7	137.8	123.2	112.5
Other leisure building	113.1	81.0	92.2	92.3	89.3	85.5	81.3	76.8	64.1

B6 - Super-stringent requirements in conjunction with replacement of windows

In order to examine the mutual impact of super-stringent component requirements, a partial scenario has been created that only examines the impact of introducing a requirement for A+ windows from 2025 onwards. In other words, there will be a requirement for an E_{ref} value of 15 kWh/m² per annum for facade windows and 20 kWh/m² per annum for roof windows. The introduction of A+ windows is expected to have good profitability, particularly in light of the price trend for windows of this type in recent years, whereby the additional cost of A-rated windows has halved in relation to C-rated windows.

The calculated heat consumption per annum in 2050 with the requirement for A+ windows as opposed to replacement from 2025 onwards, and with the trend in other building components continuing as it has to date, is 140 067 TJ per annum, corresponding to a heat saving of 66 111 TJ per annum (32.1 %).

Table 23. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of a requirement for A+ windows from 2025 in conjunction with replacement taking place as the windows reach the end of their functioning lifetime.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	125.0	114.9	106.7	99.4	93.4	81.4	73.3	60.2	53.2
Single-family dwelling	116.5	105.9	103.7	97.5	88.4	82.4	76.6	65.8	54.6
Terraced/link-detached house	106.7	101.3	95.1	90.8	78.7	73.8	70.3	62.9	53.2
Flat	94.7	94.1	95.6	94.3	88.8	82.9	82.5	65.8	44.1
Hall of residence	93.9	97.8	89.9	90.3	92.5	97.7	94.5	67.6	45.2
Residential institution	114.9	112.3	107.4	104.3	108.8	107.0	91.8	74.7	51.9
Other year-round home	100.8	105.4	101.5	105.8	96.2	92.5	69.0	63.6	50.5
Office/commercial	80.0	79.6	81.0	84.6	81.9	89.7	80.6	73.9	72.4
Hotel and service	126.2	122.2	110.2	119.7	119.8	133.7	119.8	109.3	109.8
Other commercial/ service	66.9	92.2	91.4	78.1	91.9	100.6	90.9	83.1	81.0
Cultural building	110.9	103.7	107.0	97.8	91.3	90.1	104.9	88.9	86.1
Education	82.2	88.8	97.1	91.2	97.0	114.0	92.1	83.0	75.7
Hospital	134.0	129.2	127.0	126.3	120.7	130.7	130.0	125.5	120.0
Daycare institution	117.8	129.1	124.4	128.4	129.0	128.9	117.8	115.0	107.8
Other institution	121.0	123.7	128.0	145.3	134.3	129.3	115.9	117.4	105.2
Summer house	106.6	90.8	84.4	80.8	84.2	70.5	70.9	55.1	49.5
Holiday building	91.5	103.9	115.6	77.2	84.6	75.3	77.3	52.6	27.1
Sports facility	144.8	151.4	137.4	134.9	138.0	142.0	138.5	124.0	112.9
Other leisure building	113.1	81.1	92.9	92.7	89.5	84.0	81.9	77.1	65.2

In practice, there will be a certain proportion of the total window area that will not be replaced or upgraded during the period up to 2050, even if they are single-pane windows or windows with linked frames. This is partly because of the good frame quality of these windows. It may, however, be expected that solutions will be found during this period that can ensure an appropriate level of energy efficiency for these windows at a competitive price.

The results of the analyses assume that all of the windows have been replaced or upgraded by 2050.

B7 – Automation and increasing efficiency

This scenario examines the impact of making installations more efficient, and of automation. The installation of automation and increasing the efficiency of building installations is assumed to be carried out in all major buildings, i.e. not in single-family dwellings, etc. It is assumed that these additional improvements to building installations could reduce heat consumption to a level equivalent to a 1 °C reduction in the indoor temperature, corresponding to approximately 7 % of heat consumption used for room heating.

The calculated heat consumption per annum in 2050 with this scenario will be 141 683 TJ per annum, or a reduction of 64 495 TJ per annum (31.3 %) in relation to current heat consumption.

Table 24. Calculated unit consumption in 2050 for various building types and various construction periods with 90 % compliance with the current requirements in the Building Regulations (BR10), together with implementation of automation and increasing the efficiency of building installations.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	128.0	118.0	109.9	102.6	96.9	85.0	76.7	64.0	57.4
Single-family dwelling	119.5	109.1	107.1	101.2	92.4	86.4	80.3	70.0	58.8
Terraced/link-detached house	109.8	104.5	98.4	94.5	82.6	78.1	73.7	67.0	57.5
Flat	92.9	92.4	93.8	92.8	87.9	82.1	81.1	66.4	46.1
Hall of residence	91.5	95.5	87.7	88.9	90.9	95.8	92.6	68.3	46.1
Residential institution	111.6	109.0	104.6	101.4	106.2	104.5	89.7	74.8	52.8
Other year-round home	98.4	102.9	99.2	103.0	94.8	91.3	68.2	64.6	52.0
Office/commercial	77.9	77.5	78.9	82.4	79.7	86.9	78.3	72.6	71.0
Hotel and service	121.5	117.9	106.5	115.3	115.7	129.1	115.3	105.6	106.0
Other commercial/ service	64.6	89.2	89.2	76.3	89.6	97.9	87.9	81.1	78.7
Cultural building	107.1	100.3	103.2	95.1	88.5	87.8	101.6	86.7	84.3
Education	79.9	86.4	94.5	88.8	94.3	110.2	89.3	81.7	74.3
Hospital	128.9	124.3	122.2	121.5	116.0	125.1	124.8	121.0	115.8
Daycare institution	113.8	124.6	120.1	124.0	125.1	124.8	113.9	112.0	104.9
Other institution	116.5	119.2	123.2	139.9	129.6	124.7	112.0	113.8	102.6
Summer house	110.2	94.6	89.1	85.7	89.6	75.0	76.3	61.8	57.7
Holiday building	93.7	106.0	117.9	78.8	87.8	77.8	79.9	56.2	29.5
Sports facility	138.8	145.2	132.0	129.5	131.9	135.6	132.3	119.2	108.4
Other leisure building	115.3	83.2	95.0	95.3	91.3	87.1	84.8	80.8	68.4

B8 – Super-stringent component requirements

This scenario examines the overall impact of super-stringent component requirements for roofs, external walls and windows (scenarios B1, B2 and B5).

The calculated heat consumption per annum in 2050 with this scenario will be 134 799 TJ per annum, or a reduction of 71 378 TJ per annum (34.6 %) in relation to current heat consumption.

Table 25. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of super-stringent component requirements in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime. A compliance level of 90 % is assumed for the super-stringent component requirements.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	120.9	111.0	102.8	95.8	89.8	78.2	70.7	57.5	50.4
Single-family dwelling	112.3	101.8	99.4	93.5	84.6	79.1	73.8	62.7	51.5
Terraced/link-detached house	103.3	97.9	91.9	87.5	75.0	70.3	67.7	60.3	50.6
Flat	92.2	91.6	93.0	91.8	86.3	80.4	80.2	63.6	42.0
Hall of residence	91.9	95.2	87.5	87.8	89.4	93.7	91.6	64.0	42.9
Residential institution	112.1	109.4	104.9	101.8	105.6	103.7	89.3	72.1	49.1
Other year-round home	96.5	101.6	98.0	101.9	93.1	89.5	66.5	58.4	47.3
Office/commercial	77.6	77.3	78.6	81.9	79.1	86.7	78.1	71.7	70.1
Hotel and service	123.5	119.6	107.4	117.3	116.5	130.1	117.2	107.2	108.0
Other commercial/ service	65.5	88.8	88.7	74.8	88.4	96.9	86.7	80.0	78.2
Cultural building	107.4	100.7	103.8	94.6	88.0	87.4	101.7	86.0	82.8
Education	79.7	86.2	94.4	88.2	93.6	110.5	89.2	80.0	72.9
Hospital	131.0	126.6	124.6	123.6	118.0	127.4	127.4	123.0	117.2
Daycare institution	114.7	125.6	121.3	125.2	124.7	124.5	114.2	110.9	103.8
Other institution	117.6	120.6	124.4	141.6	130.4	125.6	112.8	113.9	101.8
Summer house	100.0	84.6	76.2	71.7	74.9	59.3	61.3	46.6	40.3
Holiday building	88.0	100.4	109.8	74.5	80.9	71.9	73.6	48.1	24.7
Sports facility	140.7	148.0	133.1	131.8	134.4	138.5	135.1	120.1	109.8
Other leisure building	109.3	77.8	88.7	88.0	85.8	80.6	76.9	72.1	60.1

B9 – More stringent component requirements and A+ windows

This scenario is a combination of scenario B3 and scenario B6, and it is therefore a mean level of increased stringency in terms of the requirements for roofs and external walls together with a requirement to introduce A+ windows from 2025 onwards (please see table 17 on page 39) in conjunction with renovation and replacement. Just as in scenario B8, all windows will be replaced or upgraded to A+ windows by 2050 owing to their lifetime.

The calculated heat consumption per annum in 2050 with this scenario will be 137 163 TJ per annum, or a reduction of 69 015 TJ per annum (33.5 %) in relation to current heat consumption.

Table 26. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of more stringent component requirements in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime. This is combined with the requirement for A+ windows from 2025 onwards.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	122.8	112.8	104.6	97.5	91.5	79.7	72.0	58.7	51.7
Single-family dwelling	114.3	103.8	101.5	95.4	86.4	80.6	75.1	64.0	52.9
Terraced/link-detached house	104.9	99.5	93.4	89.1	76.7	71.9	68.9	61.5	51.8
Flat	93.5	92.9	94.3	93.1	87.5	81.6	81.3	64.7	42.9
Hall of residence	92.9	96.5	88.7	89.0	90.8	95.6	93.0	65.4	43.9
Residential institution	113.4	110.8	106.1	103.0	107.1	105.1	90.4	73.3	50.3
Other year-round home	98.5	103.4	99.7	103.7	94.5	90.9	67.6	60.2	48.4
Office/commercial	78.8	78.4	79.7	83.1	80.3	88.0	79.2	72.5	71.0
Hotel and service	124.8	120.9	108.7	118.4	117.9	131.7	118.3	108.0	108.7
Other commercial/ service	66.1	90.3	89.9	76.3	89.9	98.4	88.2	81.2	79.2
Cultural building	109.1	102.1	105.3	96.0	89.4	88.5	103.0	87.2	84.1
Education	81.0	87.5	95.7	89.6	95.1	112.0	90.5	81.2	74.0
Hospital	132.5	127.9	125.8	124.9	119.2	128.8	128.6	124.1	118.4
Daycare institution	116.2	127.3	122.7	126.7	126.6	126.4	115.7	112.4	105.3
Other institution	119.1	122.1	125.9	143.3	132.0	127.2	114.0	115.3	103.1
Summer house	103.0	87.0	78.8	74.4	77.7	62.6	64.0	48.9	42.8
Holiday building	89.7	102.0	112.0	75.7	82.4	73.4	75.0	49.5	25.6
Sports facility	142.6	149.5	134.9	133.2	135.9	140.0	136.5	121.4	110.8
Other leisure building	111.1	79.3	90.5	90.0	87.3	82.0	78.7	73.7	61.6

B10 – More stringent component requirements, A+ windows with automation and increasing efficiency

Scenario B10 is based on scenario B9, but with increasing efficiency of installations and automation. It is assumed that these additional improvements to building installations could reduce heat consumption to a level equivalent to a 1 °C reduction in the indoor temperature.

The calculated heat consumption per annum in 2050 with this scenario will be 133 695 TJ per annum, or a reduction of 72 482 TJ per annum (35.2 %) in relation to current heat consumption.

Table 27. Calculated unit consumption in 2050 for various building types and various construction periods with the introduction of more stringent component requirements and the requirement for A+ windows from 2025 onwards in conjunction with renovation and replacement taking place as the components reach the end of their functioning lifetime. The implementation of automation and increasing efficiency of building installations are also assumed.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	122.8	112.8	104.6	97.5	91.5	79.7	72.0	58.7	51.7
Single-family dwelling	114.3	103.8	101.5	95.4	86.4	80.6	75.1	64.0	52.9
Terraced/link-detached house	104.9	99.5	93.4	89.1	76.7	71.9	68.9	61.5	51.8
Flat	88.4	87.9	89.3	88.0	82.6	77.0	76.8	60.9	40.4
Hall of residence	87.9	91.3	83.9	84.2	85.8	90.4	87.9	61.6	41.3
Residential institution	107.3	104.8	100.4	97.4	101.2	99.3	85.4	69.1	47.4
Other year-round home	93.3	97.9	94.3	98.2	89.3	85.8	63.8	56.7	45.6
Office/commercial	74.6	74.3	75.5	78.6	75.9	83.2	74.8	68.5	67.0
Hotel and service	118.1	114.4	102.8	112.0	111.6	124.6	111.8	102.1	102.7
Other commercial/ service	62.5	85.4	85.0	72.1	84.9	93.1	83.4	76.7	74.9
Cultural building	103.3	96.7	99.7	90.8	84.6	83.6	97.4	82.3	79.4
Education	76.6	82.8	90.5	84.8	89.9	105.9	85.5	76.7	69.8
Hospital	125.5	121.1	119.1	118.2	112.8	121.8	121.6	117.3	111.9
Daycare institution	110.0	120.5	116.2	119.9	119.7	119.5	109.3	106.2	99.4
Other institution	112.8	115.6	119.2	135.7	124.9	120.3	107.8	108.9	97.4
Summer house	103.0	87.0	78.8	74.4	77.7	62.6	64.0	48.9	42.8
Holiday building	89.7	102.0	112.0	75.7	82.4	73.4	75.0	49.5	25.6
Sports facility	135.0	141.6	127.7	126.0	128.6	132.5	129.1	114.8	104.8
Other leisure building	111.1	79.3	90.5	90.0	87.3	82.0	78.7	73.7	61.6

C scenarios - Potential technologies

The C scenarios examine the impact of introducing new technologies in connection with selected renovation works. This scenario is also based on the savings achieved in conjunction with scenario B10, i.e. more stringent requirements for roofs and external walls and a requirement for A+ windows from 2025 in conjunction with renovation and replacement in combination with the introduction of automation and increasing efficiency of building installations. Comparisons of heat consumption in 2050 will still be made, however, with the current standards and with scenario A0, Business as usual.

C1 - Ventilation with heat recovery

This scenario shows the net heat saving with reference scenario A10 plus the establishment of mechanical ventilation with heat recovery (VGV) in conjunction with the replacement of roof cladding in large buildings (all building types other than single-family dwellings). It is assumed that 75 % of all buildings with slanted roofs can be equipped with mechanical ventilation with heat recovery. Where a major proportion is assumed not to be equipped with balanced mechanical ventilation, this is partly because some buildings already have mechanical ventilation and partly because there are some roof spaces where it is not possible to install ventilation equipment. It may therefore be assumed that 67.5 % of buildings with slanted roofs that are renovated will have balanced mechanical ventilation with heat recovery installed. The slanted roofs that are to be replaced by 2050 account for 70.5 % of the total roof area, and the roof area of large buildings accounts for 46 % of the total roof area. This means that, all other things being equal, the installation of mechanical ventilation in approximately 22 % of buildings by 2050 may be assumed.

The efficiency of the heat-recovery system is set at 90 % in homes and 85 % in other buildings. It is also assumed that the building has achieved an air density that ensures any accidental exchange of air amounts to no more than 0.13 l/s per m² (requirement for new buildings in BR10).

The calculated annual heat consumption in 2050 with the introduction of a requirement to install balanced mechanical ventilation with heat recovery in conjunction with renovations of slanted roofs is 109 342 TJ per annum. This corresponds to an annual extra heat saving in comparison with the trend to date of 96 836 TJ per annum in 2050, or a saving of 47.0 %.

On the basis of the extra quantities of ventilation air that will be generated with the introduction of balanced mechanical ventilation in conjunction with roof renovations and the minimum requirements of the Building Regulations 2010 for the efficiency of air transport, additional electricity consumption of 7 887 TJ per annum in 2050 is assumed, corresponding to approximately 1/3 of the heat saving. It may be expected that the development of better components for ventilation systems by 2050 will be able to reduce electricity consumption significantly.

Table 28 Calculated unit consumption in 2050 with the introduction of requirements concerning balanced mechanical ventilation with heat recovery in conjunction with the renovation of slanted roofs. Improvements to all other building components will be made in accordance with scenario A, i.e. at the same rate as hitherto.

kWh/m² per annum	Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006
Cottage	106.7	94.2	85.7	80.5	79.5	69.3	63.1	50.7	46.3
Single-family dwelling	101.5	85.2	82.6	78.9	75.4	70.1	65.9	55.8	47.6
Terraced/link-detached house	88.1	80.5	74.5	72.7	69.9	65.5	60.0	53.4	46.8
Flat	56.1	55.4	57.0	57.9	59.8	59.4	53.0	47.6	38.5
Hall of residence	55.2	59.1	54.1	59.8	68.5	80.4	65.0	49.6	38.8
Residential institution	75.5	72.5	68.3	66.9	77.7	80.9	62.2	53.7	45.3
Other year-round home	79.9	80.9	77.5	81.1	80.5	76.6	54.9	50.3	40.3
Office/commercial	57.5	58.0	61.3	70.7	73.1	73.8	61.9	51.0	51.1
Hotel and service	101.9	98.2	87.8	106.5	109.1	115.4	95.5	84.4	79.1
Other commercial/ service	43.9	67.3	69.0	54.7	76.9	80.7	63.8	60.5	53.0
Cultural building	78.3	69.9	74.6	72.0	71.2	54.4	73.6	47.6	52.7
Education	57.6	62.6	73.3	68.2	84.4	98.6	69.3	56.3	54.1
Hospital	105.1	97.8	96.1	110.5	111.2	119.7	107.1	96.8	89.8
Daycare institution	93.9	103.2	99.2	102.3	114.0	110.3	90.8	83.1	79.4
Other institution	99.9	98.0	102.2	127.2	120.1	105.3	88.4	84.5	79.1
Summer house	98.2	75.2	63.6	60.3	68.0	53.8	56.9	42.1	38.3
Holiday building	64.3	73.5	82.7	51.2	57.9	51.0	56.3	36.6	25.5
Sports facility	127.5	124.4	110.6	107.7	117.5	116.0	109.8	91.9	82.4
Other leisure building	105.0	68.6	77.8	77.0	80.6	71.7	61.8	52.6	43.2

Basis for data

BBR 2012

Data extracted from the BBR in September 2012 have been used for the analysis. A brief overview of the heated part of the building stock[4] is given below in relation to use, age, ownership and structure type. Buildings that are recorded in the BBR as 'Worth preserving' and buildings with 'No heat installation' have been omitted from the area calculations, since they are irrelevant to the present analysis of potential net heat savings[5]. Of the building categories included in the analysis, the omitted area accounts for approximately 4 % of the heated area.

Age of building stock

Figure 17 shows the heated area calculated according for the calculation period determined on the basis of typical periods with regard to building customs (the oldest periods) and following increases in the stringency of the Building Regulations (later periods).

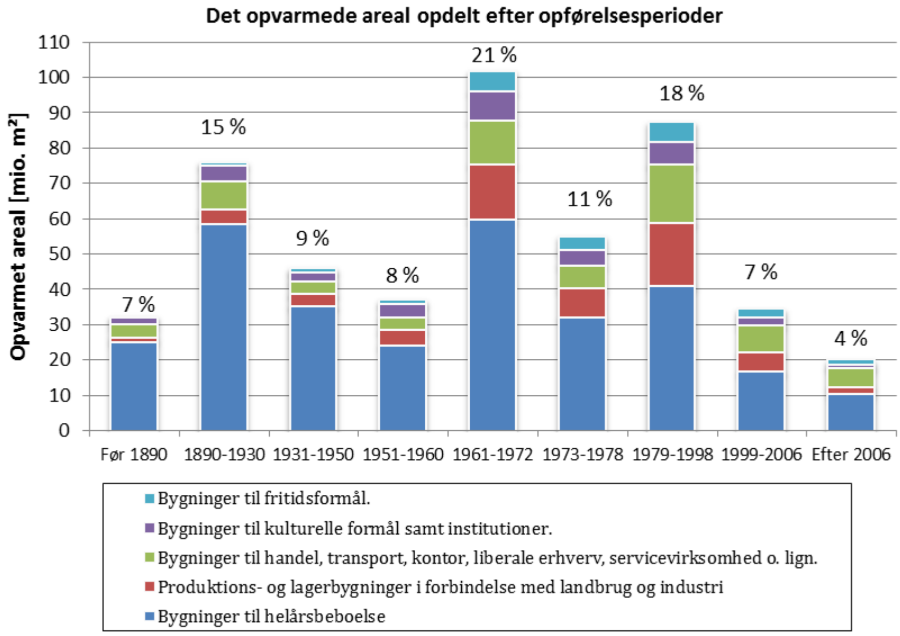

Figure 17. The heated area calculated by calculation period and main use groups. Buildings without heat installations and protected buildings are not included.

[4] The heated area of the building stock is determined by finding the sum of the BBR fields BUILD_HOME_ANNU_COMPIL and COMMERC_ANNU_COMPIL.
[5] Please see the calculation of protected heated area and area without any heat installation in the annexed report.

Danish	English
Det opvarmede areal opdelt efter opførelsesperioder	Heated area by construction period
Opvarmet areal [mio. m^2]	Heated area [million m^2]
Før 1890	Before 1890
Efter 2006	After 2006
Bygninger til fritidsformål.	Buildings for leisure purposes.
Bygninger til kulturelle formål samt institutioner.	Buildings for cultural purposes, and institutions.
Bygninger til handel, transport, kontor, liberale erhverv, servicevirksomhed o. lign.	Buildings for commerce, transport, offices, liberal professions, service activities, etc.
Produktions- og lagerbygninger i forbindelse med landbrug og industri	Production and storage buildings connected to agriculture and industry
Bygninger til helårsbeboelse	Buildings for year-round residence

It may be seen from figure 17 that a large proportion of the heated area was built during the 1890-1930 period (15 %) and is thus approximately 100 years old. These buildings face comprehensive renovations and maintenance with consequent requirements to upgrade their insulation capacity. The 1961-1978 periods also represent a large number of buildings that are approaching a stage where they will face renovation or replacement of building components. The 1979-1998 period also includes a larger number of buildings, but the profitability of the improvements with the greatest potential is expected to be limited in these buildings, and the requirements for post-installation insulation of roofs and external walls will therefore not be relevant.

Ownership of the building stock

As may be seen from figure 18, only approximately 7 % of the heated area is owned by the public sector, i.e. local government, regional government (recorded as county councils) and the State. This is interesting in terms of a general assessment of whether the insulation standard of publicly-owned areas generally differs from that of similar buildings of the same type and age in private ownership.

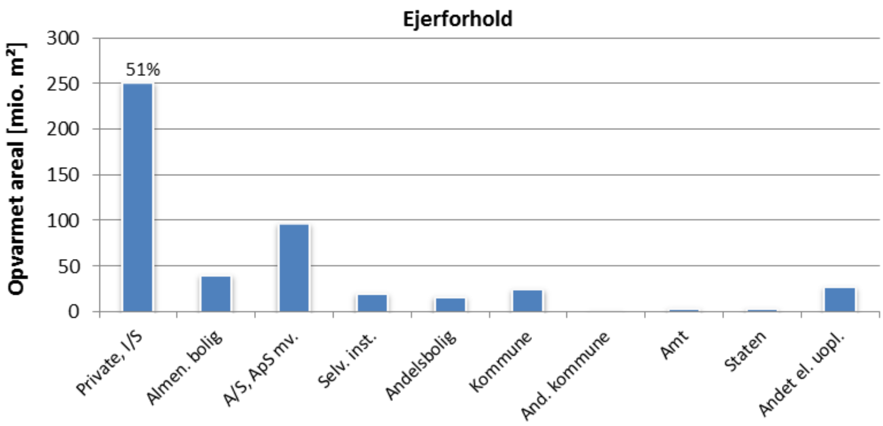

Figure 18. The heated area calculated by ownership.

Danish	English
Ejerforhold	Ownership
Opvarmet areal [mio. m^2]	Heated area [million m^2]
Private, I/S	Private individuals, I/S
Almen, bolig	General, homes
A/S, ApS mv.	A/S, ApS, etc.
Selv. inst.	Self-owned institutions
Andelsbolig	Part-owned home
Kommune	Local government
And. kommune	Other local government
Amt	County council
Staten	State
Andet el. uopl.	Other or unknown

Structures in the building stock

The BBR records the roof-cladding and external-wall materials of buildings. The associated area is not recorded, however, and the calculations may therefore be linked to the heated or built area. This distribution key is calculated on the basis of records in the EMO database, which contains information on all of these areas.

The distribution of the built area calculated according to the various roof-cladding materials is shown in figure 19 for five main building-use types. The built area[6] is assumed to be comparable to the insulated loft area.

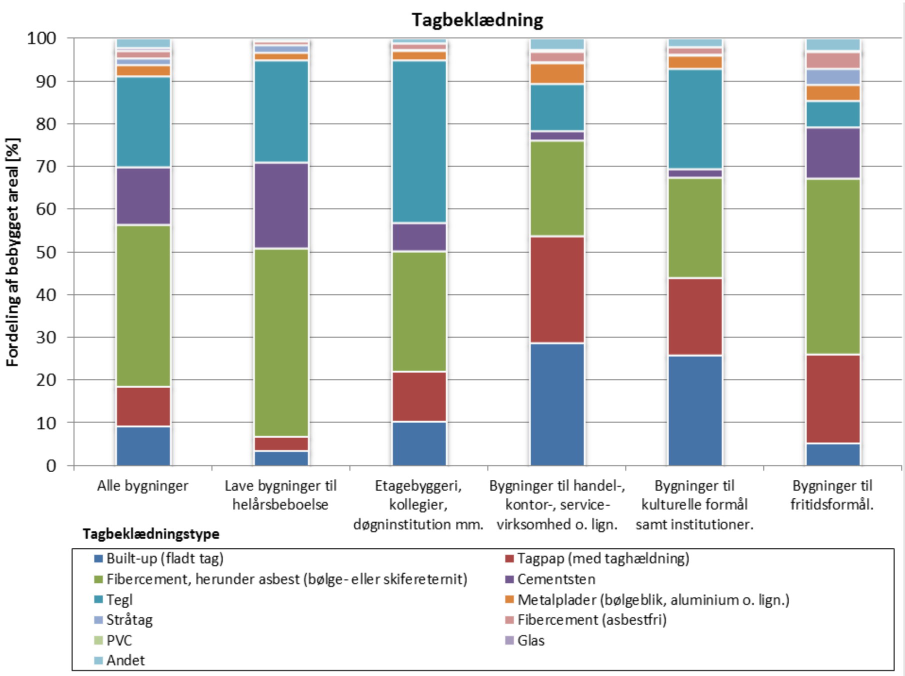

Figure 19. Distribution of the built area according to roof-cladding type calculated for all buildings and sub-groups of main building-use types.

[6] The built area corresponds to the area on the ground that is built on (the footprint of the building).

Danish	English
Tagbeklædning	Roof cladding
Fordeling af bebygget areal [%]	Distribution of built area [%]
Alle bygninger	All buildings
Lave bygninger til helårsbeboelse	Low buildings for year-round residence
Etagebyggeri, kollegier, døgnsinstitution mm.	Flats, halls of residence, residential institutions, etc.
Bygninger til handel-, kontor-, servicevirksomhed o. lign.	Buildings for commerce, offices, service activities, etc.
Bygninger til kulturelle formål samt institutioner.	Buildings for cultural purposes, and institutions.
Bygninger til fritidsformål.	Buildings for leisure purposes.
Tagbeklædningstype	Roof-cladding type
Built-up (fladt tag)	Built-up (flat roof)
Fibercement, herunder asbest (bølge- eller skifereternit)	Fibreglass cement, including asbestos (corrugated or slate asbestos cement)
Tegl	Tiles
Stråtag	Thatched roof
Andet	Other
Tagpap (med taghældning)	Felt board (with roof pitch)
Cementsten	Breeze block
Metalplader (bølge blik, aluminium o. lign.)	Metal sheets (corrugated tin plate, aluminium, etc.)
Fibercement (asbestfri)	Fibreglass cement (asbestos-free)
Glas	Glass

Figure 20 shows the distribution of the heated floor area calculated according to various types of external-wall cladding. It may be seen that approximately 80 % of the heated area in most building types is calculated using external walls of tile or concrete. The long lifetime of tiles and the general unwillingness to change the appearance of external walls of this type will completely dominate the scope of renovation and thus the potential savings calculated.

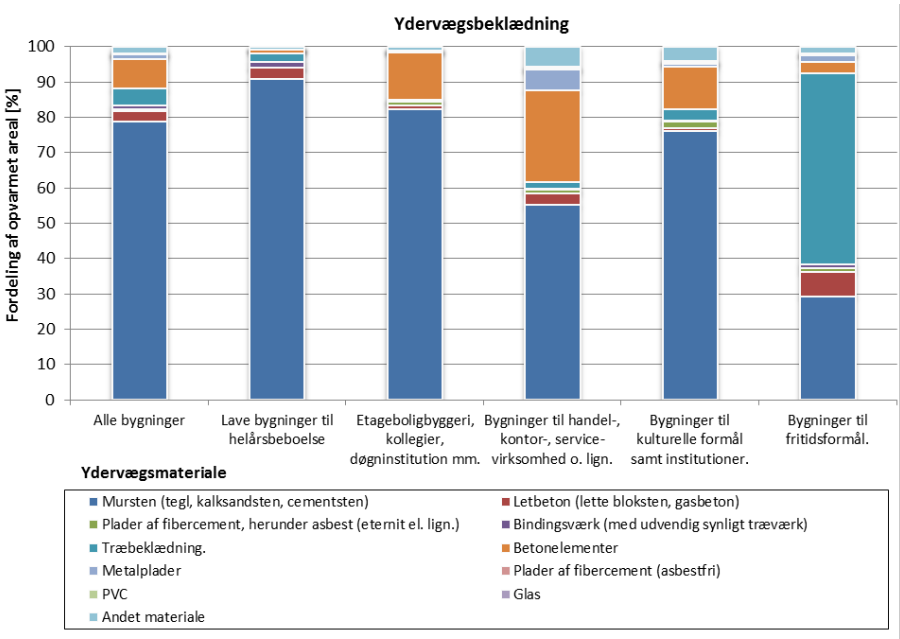

Figure 20. Distribution of the heated area according to external-wall-cladding type calculated for all buildings and sub-groups of main building-use types.

Danish	English
Ydervægsbeklædning	External-wall cladding
Fordeling af opvarmet areal [%]	Distribution of heated area [%]
Alle bygninger	All buildings
Lave bygninger til helårsbeboelse	Low buildings for year-round residence
Etagebyggeri, kollegier, døgnsinstitution mm.	Flats, halls of residence, residential institutions, etc.
Bygninger til handel-, kontor-, servicevirksomhed o. lign.	Buildings for commerce, offices, service activities, etc.
Bygninger til kulturelle formål samt institutioner.	Buildings for cultural purposes, and institutions.
Bygninger til fritidsformål.	Buildings for leisure purposes.
Ydervægsbeklædningstype	External-wall-cladding type
Mursten (tegl, kalksandsten, cementsten)	Bricks (tiles, sand-lime bricks, and breeze block)
Plader af fibercement, herunder asbest (eternit el. lign.)	Fibreglass-cement sheets, including asbestos (asbestos cement, etc.)
Træbeklædning	Timber cladding
Metalplader	Metal sheets
Andet materiale	Other material
Letbeton (lette bloksten, gasbeton)	Light concrete (light stone blocks and aerated concrete)
Bindingsværk (med udvendig synligt træværk)	Frame wall (with externally visible timber)
Betonelementer	Concrete elements
Plader af fibercement (asbestfri)	Fibreglass-cement sheets (asbestos-free)
Glas	Glass

Energy-labelling data 2012

Building models have been created for individual subsidiary quantities of the Danish building stock, based on data from the Energy-Labelling Scheme (EMO).

Where there are sufficient data to identify every single construction period with certainty in these subsidiary quantities, this has been done. For the subsidiary quantities with more limited information, models have only been created that cover all construction periods for the building use in question.

This is a snapshot of the Danish building stock based on information obtained in 2006, when the current energy-labelling scheme started, up to the summer of 2012. The snapshot is therefore based on information obtained in conjunction with the energy-labelling of existing buildings in conjunction with sale or letting. There is some uncertainty associated with the scope of changes, in the form of post-installation insulation and window replacement, carried out after a new owner has taken possession of a building, and these are therefore not recorded in the EMO database.

Every subsidiary quantity of the building stock characterises a model for the construction and energy condition of that quantity, and it is used to calculate the expected heat consumption and potential heat savings.

Area-weighted U values

The area-weighted heat-loss coefficient (U value) of the structures has been calculated to generate a model of the building stock as a whole. Figure 21 to Figure 24 show the U values calculated for the nine construction periods for selected building types.

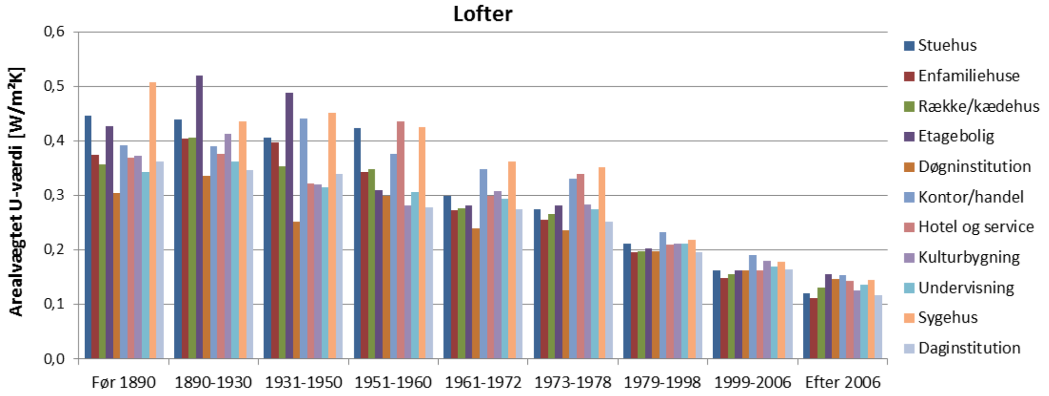

Figure 21. Calculated area-weighted U values for roof and loft structures based on the EMO.

Danish	English
Lofter	Lofts
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Stuehus	Cottage
Enfamiliehuse	Single-family dwellings
Række/kædehus	Terraced/link-detached house
Etagebolig	Flat
Døgninstitution	Residential institution
Kontor/handel	Office/commerce
Hotel og service	Hotel and service
Kulturbygning	Cultural building
Undervisning	Education
Sygehus	Hospital
Daginstitution	Daycare institution

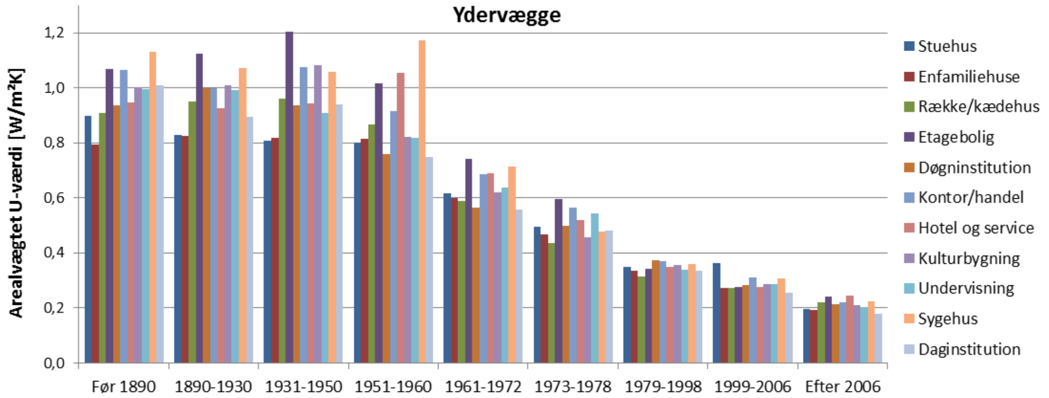

Figure 22. Calculated area-weighted U values for external walls based on the EMO.

Danish	English
Ydervægge	External walls
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Stuehus	Cottage
Enfamiliehuse	Single-family dwellings
Række/kædehus	Terraced/link-detached house
Etagebolig	Flat
Døgninstitution	Residential institution
Kontor/handel	Office/commerce
Hotel og service	Hotel and service
Kulturbygning	Cultural building
Undervisning	Education
Sygehus	Hospital
Daginstitution	Daycare institution

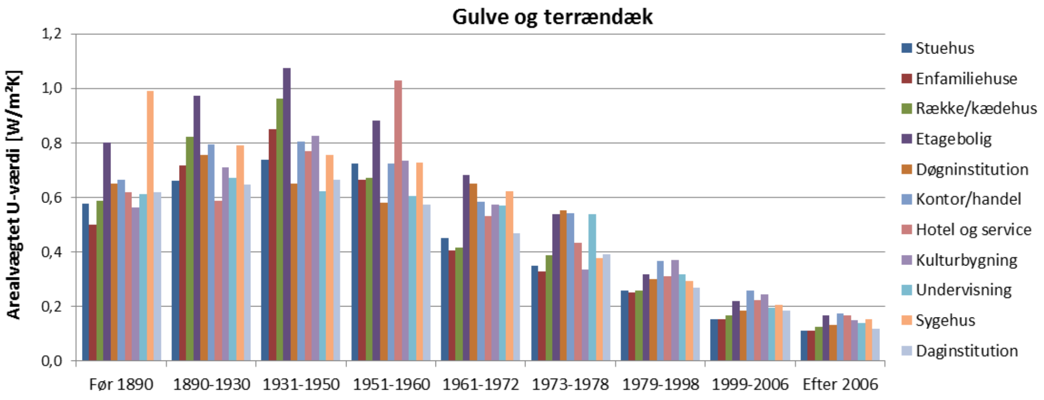

Figure 23. Calculated area-weighted U values for floors and floor slabs based on the EMO.

Danish	English
Gulve og terrændæk	Floors and floor slabs
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Stuehus	Cottage
Enfamiliehuse	Single-family dwellings
Række/kædehus	Terraced/link-detached house
Etagebolig	Flat
Døgninstitution	Residential institution
Kontor/handel	Office/commerce
Hotel og service	Hotel and service
Kulturbygning	Cultural building
Undervisning	Education
Sygehus	Hospital
Daginstitution	Daycare institution

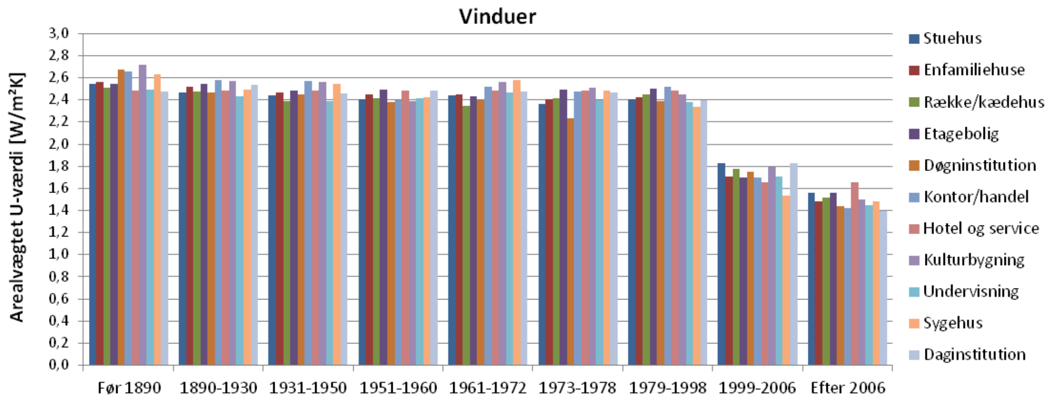

Figure 24. Calculated area-weighted U values for windows based on the EMO.

Danish	English
Vinduer	Windows
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Stuehus	Cottage
Enfamiliehuse	Single-family dwellings
Række/kædehus	Terraced/link-detached house
Etagebolig	Flat
Døgninstitution	Residential institution
Kontor/handel	Office/commerce
Hotel og service	Hotel and service
Kulturbygning	Cultural building
Undervisning	Education
Sygehus	Hospital
Daginstitution	Daycare institution

The area-weighted mean U values for the structures are used in the model for the current transmission loss of the building stock. An area-weighted U value is also calculated for the renovated building stock, which is used to calculate the total transmission loss of the building stock in 2050.

Insulation level and ownership

The figures below show the area-weighted U values for lofts, external walls, floors and windows specific to buildings used for offices/commerce (use code 320) and for education (use code 420), since the proportion of publicly-owned buildings is most significant for these uses.

The following definition of ownership is used (please see the user codes specified in the BBR):

Privately-owned: Private individuals, I/S, A/S, ApS, general homes, self-owned institutions, part-owned homes, and other

Publicly-owned: Local government, Other local government, County Councils (now regions), the State

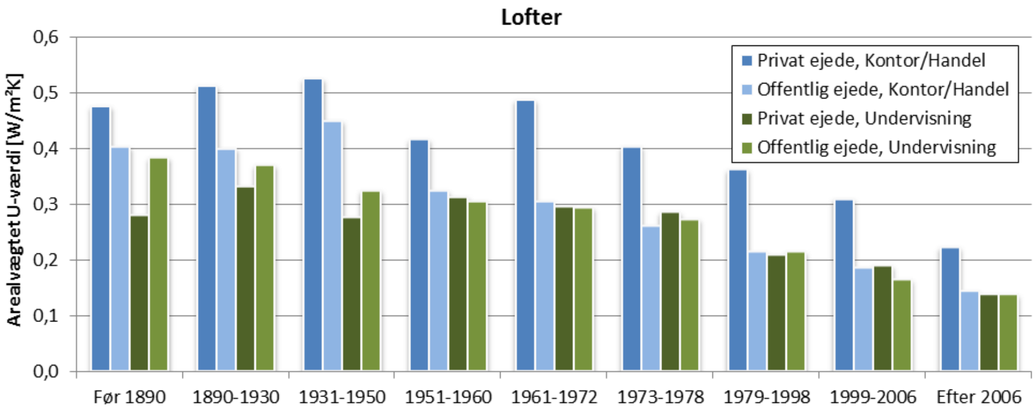

Figure 25. Area-weighted U values for lofts calculated according to ownership.

Danish	English
Lofter	Lofts
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Privat ejede, Kontor/Handel	Privately-owned, Office/Commerce
Offentlig ejede, Kontor/Handel	Publicly-owned, Office/Commerce
Privat ejede, Undervisning	Privately-owned, Education
Offentlig ejede, Undervisning	Publicly-owned, Education

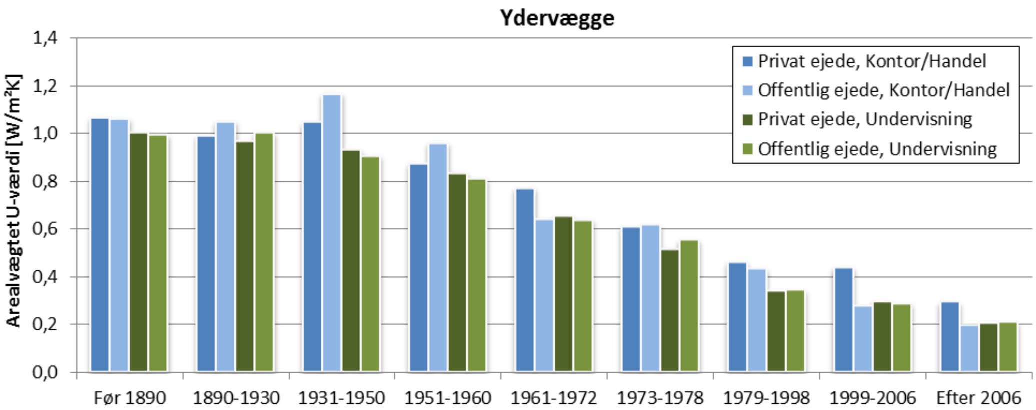

Figure 26. Area-weighted U values for external walls calculated according to ownership.

Danish	English
Ydervægge	External walls
Arealvægtet U-værdi [W/m²K]	Area-weighted U value [W/m²K]
Før 1890	Before 1890
Efter 2006	After 2006
Privat ejede, Kontor/Handel	Privately-owned, Office/Commerce
Offentlig ejede, Kontor/Handel	Publicly-owned, Office/Commerce
Privat ejede, Undervisning	Privately-owned, Education
Offentlig ejede, Undervisning	Publicly-owned, Education

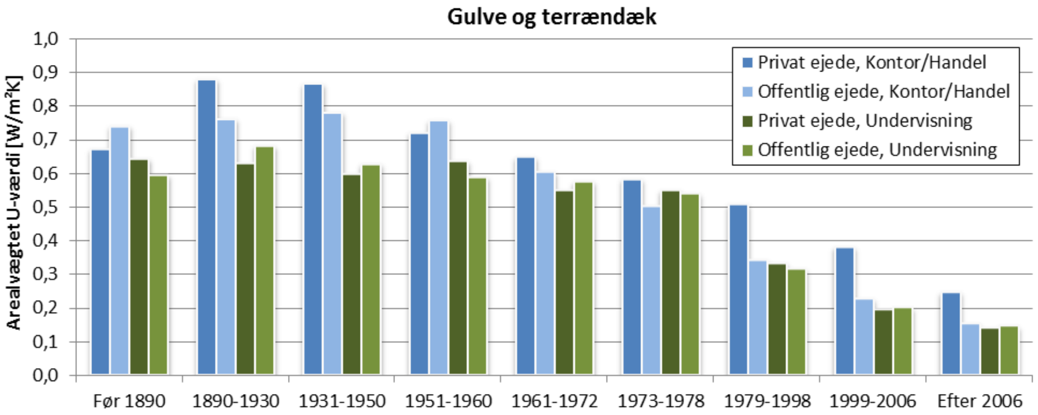

Figure 27. Area-weighted U values for floors and floor slabs calculated according to ownership.

Danish	English
Gulve og terrændæk	Floors and floor slabs
Arealvægtet U-værdi [W/m²K]	Area-weighted U value [W/m²K]
Før 1890	Before 1890
Efter 2006	After 2006
Privat ejede, Kontor/Handel	Privately-owned, Office/Commerce
Offentlig ejede, Kontor/Handel	Publicly-owned, Office/Commerce
Privat ejede, Undervisning	Privately-owned, Education
Offentlig ejede, Undervisning	Publicly-owned, Education

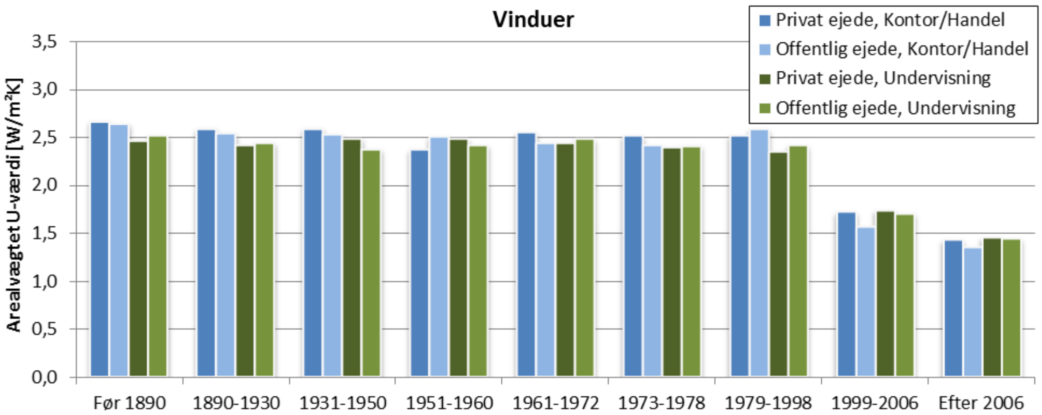

Figure 28. Area-weighted U values for windows calculated according to ownership.

Danish	English
Vinduer	Windows
Arealvægtet U-værdi [W/m^{2}K]	Area-weighted U value [W/m^{2}K]
Før 1890	Before 1890
Efter 2006	After 2006
Privat ejede, Kontor/Handel	Privately-owned, Office/Commerce
Offentlig ejede, Kontor/Handel	Publicly-owned, Office/Commerce
Privat ejede, Undervisning	Privately-owned, Education
Offentlig ejede, Undervisning	Publicly-owned, Education

In general terms, there is no significant difference between the two owner types, although privately-owned office and commercial buildings generally have poorer loft/roof insulation than publicly-owned buildings in the same category.

Renovation and replacement of building components

The estimated heat saving and cost of renovating individual building components are based on a marginal cost. In other words, this is the additional cost associated with implementing the heat saving, i.e. the work directly associated with post-installation insulation work, but not the work and costs that would already have been done and incurred for general, planned building renovations.

The costs will also depend on the scope of the work. A calculated mean area for the building category in question is used to define the scope of the work. It depends on the built area and the heated area (home + commercial area).

Roofs

On the basis of the lifetimes described earlier (table 4), a model has been created for the scope (calculated as the built area) of the total annual replacement of roof cladding by 2050. The model has been created on the basis of information from the BBR concerning the type of roof cladding involved and thus indirectly the lifetime of the roof cladding, and the year in which the building was constructed.

It is assumed that the roofs on buildings older than the mean lifetime of the roof cladding will already have been replaced at least once during the lifetime of the building. The area of these roofs, which will also have to be replaced in the future, is also included every year as the reciprocal value of the lifetime of the roof-cladding type in question multiplied by the total area. Roof cladding with a short lifetime, i.e. types that must be replaced more than once by 2050, are only included once in the total area that is insulated following its installation. It is assumed that the roof will not be insulated following its installation until it is renovated. This is the reason for the fall in roof area that must be renovated, with the consequent heat savings towards the end of the period under consideration (please see figure 29). Approximately 81 % of the total roof area will thus be renovated with the potential opportunity of carrying out post-installation insulation at the same time, by 2050 (please also see table 10 on page 28).

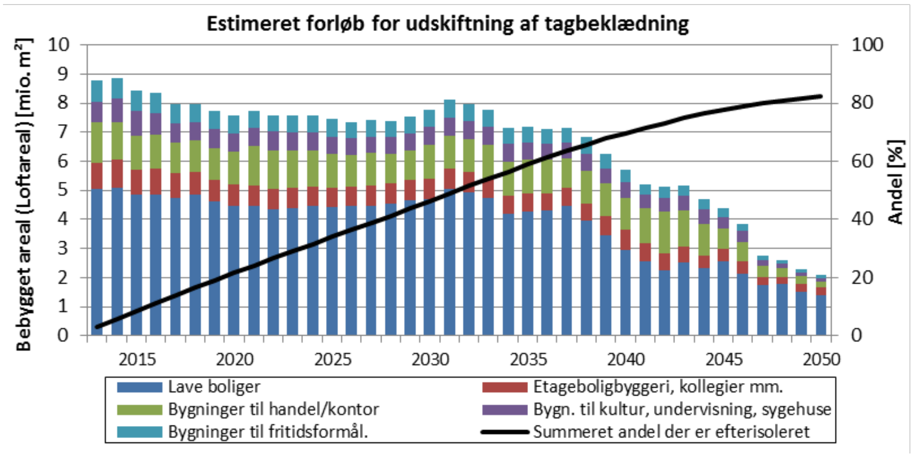

Figure 29. Estimated trend in the extent to which roof cladding is replaced, with potential associated post-installation insulation (based on BBR information concerning the roof type, year of construction, and assumption concerning mean lifetimes for the different types of roof). Roof cladding that must be replaced several times by 2050 is only included the first time this happens, which explains the fall towards the end of the period under consideration.

Danish	English
Estimeret forløb for udskiftning af tagbeklædning	Estimated progress of roof-cladding replacement
Bebygget areal (Loftareal) [mio. m^2]	Built area (Loft area) [million m^2]
Andel [%]	Proportion [%]
Lave boliger	Low homes
Bygninger til handel/kontor	Buildings for commerce/offices
Bygninger til fritidsformål.	Buildings for leisure purposes.
Etageboligbyggeri, kollegier mm.	Blocks of flats, halls of residence, etc.
Bygn. til kultur, undervisning, sygehuse	Cultural buildings, education, hospitals
Summeret andel der er efterisoleret	Total proportion insulated following installation

With this assumption, the roofs that have not been insulated following their installation in conjunction with the first roof replacement on the grounds of technical barriers or non-compliance with the requirements in the Building Regulations will also not be insulated following their installation when the roof is replaced the second time. Therefore, only non-compliance with the BR requirements is included in the calculation, and this means that the potential savings have been slightly underestimated.

As may be seen from figure 29, low homes account for the vast majority of roof-cladding replacement. The vast majority of roof-renovation tasks therefore fall within the single-family dwellings segment.

External walls

The vast majority of external wall area of the building stock consists of tiled walls, which are found in a total of approximately 80 % of the total heated area. Tiled walls have a relatively long lifetime and it is often difficult to provide them with post-installation insulation without changing the architectonic impression of the building. This limits the extent to which the area is renovated with appropriate post-installation insulation for external walls of this type. Some of the tiled external-wall area will, however, undergo post-installation insulation, and it is assumed that this will increase towards 2050. On average, it is assumed that 0.5 % of the total tiled external-wall area will be renovated and undergo post-installation insulation each year for all types of building use. This is, for example, equivalent to the renovation of approximately 7 000 single-family dwellings and approximately 250 blocks of flats with tiled external walls each year.

For the other types of external-wall cladding (such as timber cladding), the lifetime is shorter and a model may therefore be created for future replacement based on the same method as for roof cladding. The model that has been created for the replacement of external walls may be seen in figure 30. Just as for roof cladding, there are some instances of external-wall cladding that have a shorter lifetime than the duration of the period under consideration. These will only be included the first time they occur, since it is assumed that post-installation insulation will only be carried out at that time, and that the insulation will not be increased during the next renovation. Approximately 18 % of the total external-wall area will be renovated during the period under consideration with the potential for post-installation insulation at the same time.

If the external-wall area undergoing post-installation insulation is to be increased, it is imperative that solutions be found to safeguard the architectonic impression of tiled external walls that have undergone post-installation insulation, or that safe methods be found for internal post-installation insulation. Alternatively, the view that tiled external walls may not be changed for architectonic reasons will have to be reckoned with.

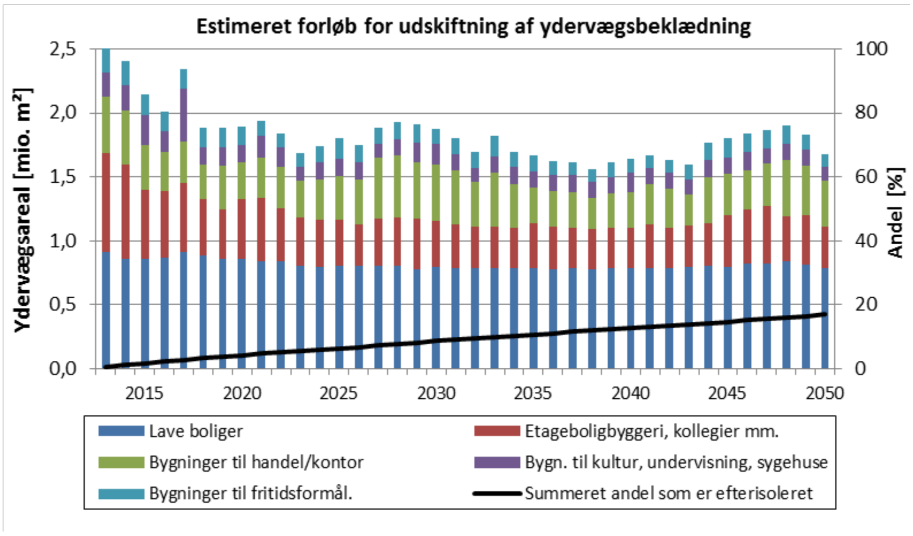

Figure 30. Estimated progress of replacement of external-wall cladding based on BBR information on the type of external-wall cladding, the year in which the building was constructed, and assuming mean lifetimes for various cladding types.

Danish	English
Estimeret forløb for udskiftning af ydervægsbeklædning	Estimated progress of external-wall-cladding replacement
Ydervægsareal [mio. m^2]	External-wall area [million m^2]
Andel [%]	Proportion [%]
Lave boliger	Low homes
Bygninger til handel/kontor	Buildings for commerce/offices
Bygninger til fritidsformål.	Buildings for leisure purposes.
Etageboligbyggeri, kollegier mm.	Blocks of flats, halls of residence, etc.
Bygn. til kultur, undervisning, sygehuse	Cultural buildings, education, hospitals
Summeret andel der er efterisoleret	Total proportion insulated following installation

Just as for roofs, the cost of post-installation insulation of external walls is divided into a limited number of groups, namely heavy facades (tiles and concrete), tiles with cavity walls, and light facades.

Floor structures

It is not possible to estimate the extent to which floors are replaced on the bottom floor or floor structures adjacent to unheated spaces or ventilation spaces in Danish buildings. Accordingly, it is also not possible to set out any expectation concerning the renovation of floors during the period up to 2050, as has been done for roofs and external walls.

If there is immediate access to cellars or ventilation spaces, however, it is often financially profitable or appropriate in terms of comfort to carry out post-installation insulation, even when this is not done in conjunction with other planned works. It is assumed that 15 % of the area above cellars and ventilation spaces will undergo post-installation insulation by 2050, with the same proportion being done each year.

Windows and external doors

It is not possible to separate doors in external walls from windows in the data from the Energy-Labelling Scheme, so these are considered together in calculating the total scope of renovation works.

The lifetime of windows and double-glazed units is limited, and much shorter than for other building components. The model that has been created for the future replacement of windows may be seen in figure 31. Approximately 150 % of the total area of windows and external doors will be replaced during the period under consideration. In contrast with the other building components, the second replacement during the period under consideration could also result in a heat saving, since there will be developments in the requirements laid down in the Building Regulations over time, and further technical developments can also be expected in the insulation capacity of windows by 2050.

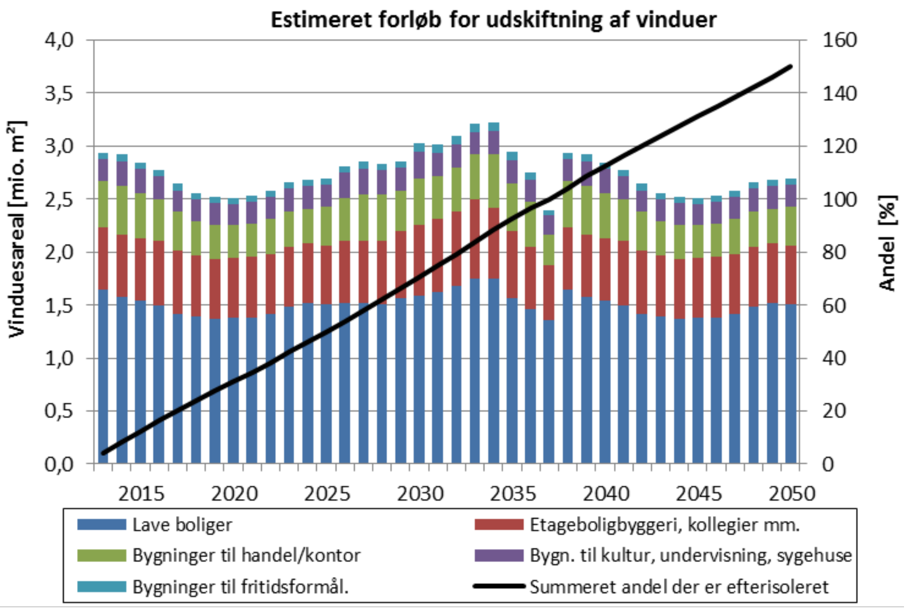

Figure 31. Estimated progress of window replacement based on a mean lifetime of 25 years.

Danish	English
Estimeret forløb for udskiftning af vinduer	Estimated progress of window replacement
Vinduesareal [mio. m^2]	Window area [million m^2]
Andel [%]	Proportion [%]
Lave boliger	Low homes
Bygninger til handel/kontor	Buildings for commerce/offices
Bygninger til fritidsformål.	Buildings for leisure purposes.
Etageboligbyggeri, kollegier mm.	Blocks of flats, halls of residence, etc.
Bygn. til kultur, undervisning, sygehuse	Cultural buildings, education, hospitals
Summeret andel der er efterisoleret	Total proportion insulated following installation

References

[1] Aggerholm, S. & Grau, K. (2011). Energy needs of buildings (SBi communication 213, second edition, 2011). Danish Building Research Institute, Aalborg University, Hørsholm.

[2] Buildings and Housing Register (BBR) (2012). Danish Energy Agency version, January 2012

[3] Building Regulations 2010 (1 January 2014) (2010). Business and Construction Authority, Copenhagen.

[4] Christensen, T.H.; Jensen, J.O. & Gram-Hanssen, K. (2013). Compliance with the requirements of the Building Regulations (SBi 2013:02). Danish Building Research Institute, Aalborg University, Copenhagen.

[5] Energy-Labelling Scheme database (2012). Joint Secretariat for Surveillance and Labelling Schemes.

[6] Energy Parcel – demonstration project, Realdania BYG. Localised on 3 April 2014 at http://www.realdaniabyg.dk/projekter/energiparcel

[7] Energy Statistics 2011 (2013). Danish Energy Agency.

[8] Landowners' Investment Fund. Localised on 3 April 2014 at www.levetider.dk

[9] Energy Renovation Network (May 2013). Initiative Catalogue.

[10] Energy Renovation Network (April 2013). Basic catalogue of network groups – 156 specific proposals for initiatives to promote energy renovations.

[11] Rose, J. & Mortensen, L. H. (2013). Future-proofing component requirements (SBi 2013:03). Danish Building Research Institute, Aalborg University, Copenhagen.

[12] V&S price data (2012). Danish Building Centre.

[13] Wittchen, K. B. (2009). Potential energy savings in existing construction (SBi 2009:05). Danish Building Research Institute, Aalborg University, Hørsholm.

[14] Wittchen, K. B. & Kragh, J. (2050). Energy needs of Danish buildings in 2050 (SBi 2010:56). Danish Building Research Institute, Aalborg University, Hørsholm.

[15] Wittchen, K.B. & Kragh, J. (2013). Heat savings during ongoing renovations of buildings until 2050 (SBi 2013:08). Danish Building Research Institute, Aalborg University. Copenhagen.

[16] Larsen, E.S. (1992). Lifetime of concrete structures (SBi report 225). Danish Building Research Institute, Hørsholm.

Annex 1 – Data from the BBR and EMO

A number of key figures used to create the calculation model for the total net heat consumption of the building stock are described below. The model is largely based on the records in the Energy-Labelling Scheme (EMO) database. table 29 shows the proportion of the EMO database that covered the total building stock, in relation to both the number of buildings and the heated area.

Table 29. Total heated area (sum of residential area and commercial area). Buildings without heat installations and protected buildings are not included. Agricultural and commercial buildings are also excluded.

		Number			Heated area		
		BBR [-]	EMO [-]	Labelled proportion [%]	BBR [m²]	EMO [m²]	Labelled proportion [%]
Cottage	110	117 896	9 160	8	21 967 559	1 817 481	8
Single-family dwelling	120	1 083 295	171 765	16	156 856 239	26 731 851	17
Terraced/link-detached house	130	232 943	41 816	18	35 066 558	10 296 953	29
Flat	140	87 735	25 690	29	81 601 987	41 893 958	51
Hall of residence	150	1 749	304	17	1 379 430	581 913	42
Residential institution	160	4 192	1 697	40	4 266 434	2 506 076	59
Other year-round home	190	5 018	354	7	636 274	146 630	23
Office/commercial	320	56 304	7 533	13	57 230 749	17 876 342	31
Hotel and service	330	11 561	889	8	6 058 006	1 187 392	20
Other commercial/service	390	1 851	206	11	789 044	215 921	27
Cultural building	410	8 585	1 574	18	4 197 662	1 428 209	34
Education	420	17 050	5 751	34	21 680 224	14 336 129	66
Hospital	430	2 199	913	42	4 393 353	3 059 133	70
Daycare institution	440	7 728	4 173	54	3 372 557	2 237 136	66
Summer house	510	211 751	705	0	15 805 344	81 244	1
Holiday building	520	3 408	150	4	768 785	118 583	15
Sports facility	530	6 545	1 296	20	5 605 194	2 079 600	37
Other leisure building	590	9 230	841	9	1 369 166	366 797	27

Heated area by construction period and building use

Table 30 shows a calculation of the total heated area for buildings with heat installations. Similarly, table 31 shows the heated area excluding buildings categorised as protected or worth preserving, and buildings without any heat installation.Table 31 therefore shows the potential heated area where heat savings can be achieved in conjunction with energy renovations.

Table 30. Total heated area [m²], including areas from protected buildings and buildings worth preserving that have heat installations (data from BBR 2012).

Use code		Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006	Total
Cottage	110	7 232 815	8 833 785	2 150 271	737 804	787 751	632 889	967 513	459 339	418 239	22 220 406
Single-family dwelling	120	11 082 993	26 433 186	16 151 211	12 769 063	38 567 879	22 152 767	17 801 805	7 386 259	5 068 685	157 413 848
Terraced/link-detached house	130	1 575 126	2 338 394	1 892 749	2 191 133	4 653 503	3 764 218	12 908 011	4 091 722	1 986 454	35 401 310
Flat	140	6 252 303	20 773 880	15 051 075	8 012 426	14 202 116	4 495 472	7 931 108	3 822 652	2 414 296	82 955 328
Hall of residence	150	25 710	73 889	65 226	78 961	531 850	132 778	251 140	162 015	71 474	1 393 043
Residential institution	160	156 181	417 543	266 202	357 347	828 741	651 643	853 879	550 289	262 878	4 344 703
Other year-round home	190	141 569	181 327	59 849	39 527	66 240	33 066	73 929	50 990	22 393	668 890
Office/commercial	320	3 920 304	6 915 883	3 099 172	2 902 902	10 525 416	5 741 957	14 140 062	6 625 526	4 809 281	58 680 503
Hotel and service	330	910 931	1 334 008	440 258	425 749	972 913	397 251	1 123 268	421 999	256 084	6 282 461
Other commercial/service	390	20 249	71 979	59 211	45 150	121 696	79 942	208 598	124 003	69 227	800 055
Cultural building	410	1 252 807	983 826	275 290	225 808	419 507	309 904	804 794	291 443	117 099	4 680 478
Education	420	841 205	2 407 049	1 558 873	2 747 263	6 015 213	2 961 435	3 555 984	1 387 119	505 792	21 979 933
Hospital	430	209 661	614 150	413 452	378 625	943 686	797 299	721 180	263 829	129 900	4 471 782
Daycare institution	440	126 731	343 573	212 858	242 152	722 136	303 894	996 430	318 218	132 395	3 398 387
Other institution	490	121 234	225 353	126 813	141 832	196 262	77 926	185 277	71 770	45 619	1 192 086
Summer house	510	369 392	482 896	900 004	951 282	4 304 716	2 649 158	3 419 076	1 686 100	1 062 886	15 825 510
Holiday building	520	49 014	120 787	80 534	64 321	100 219	102 027	189 170	43 054	29 149	778 275
Sports facility	530	42 916	186 296	223 745	218 665	1 350 327	1 003 505	1 740 745	556 705	323 538	5 646 442
Other leisure building	590	87 712	228 277	90 578	58 231	159 369	109 259	403 954	159 460	82 775	1 379 615
Total	All	34 418 853	72 966 081	43 117 371	32 588 241	85 469 540	46 396 390	68 275 923	28 472 492	17 808 164	429 513 055

Table 31 Heated area [m^2] excluding areas from protected buildings and buildings worth preserving, and buildings that have no heat installations (data from BBR 2012).

Use code		Before 1890	1890-1930	1931-1950	1951-1960	1961-1972	1973-1978	1979-1998	1999-2006	After 2006	Total
Cottage	110	6 992 580	8 822 187	2 150 071	736 990	787 751	632 889	967 513	459 339	418 239	21 967 559
Single-family dwelling	120	10 857 761	26 276 530	16 046 684	12 724 246	38 548 900	22 149 190	17 798 372	7 385 871	5 068 685	156 856 239
Terraced/link-detached house	130	1 434 902	2 242 544	1 843 127	2 167 001	4 636 067	3 762 160	12 902 650	4 091 653	1 986 454	35 066 558
Flat	140	5 502 383	20 523 978	14 816 391	7 920 487	14 178 249	4 494 265	7 929 286	3 822 652	2 414 296	81 601 987
Hall of residence	150	17 271	71 790	62 151	78 961	531 850	132 778	251 140	162 015	71 474	1 379 430
Residential institution	160	126 511	413 100	254 058	354 833	815 948	646 509	842 702	549 895	262 878	4 266 434
Other year-round home	190	109 846	180 542	59 741	39 527	66 240	33 066	73 929	50 990	22 393	636 274
Office/commercial	320	2 882 306	6 642 212	3 029 752	2 866 171	10 511 374	5 732 085	14 132 042	6 625 526	4 809 281	57 230 749
Hotel and service	330	742 549	1 288 002	436 902	425 228	966 811	397 163	1 123 268	421 999	256 084	6 058 006
Other commercial/service	390	19 572	61 645	59 211	45 150	121 696	79 942	208 598	124 003	69 227	789 044
Cultural building	410	886 101	896 886	262 585	218 758	411 370	309 294	804 126	291 443	117 099	4 197 662
Education	420	651 790	2 349 593	1 540 402	2 725 945	6 008 478	2 961 339	3 549 766	1 387 119	505 792	21 680 224
Hospital	430	144 143	611 484	412 817	378 625	936 151	795 224	721 180	263 829	129 900	4 393 353
Daycare institution	440	117 079	337 523	210 396	237 114	720 075	303 894	995 863	318 218	132 395	3 372 557
Other institution	490	65 766	216 882	125 813	141 832	190 891	77 926	185 277	71 770	45 619	1 121 776
Summer house	510	352 544	480 910	899 589	951 107	4 304 471	2 649 090	3 418 647	1 686 100	1 062 886	15 805 344
Holiday building	520	42 927	118 773	80 534	63 609	100 219	102 027	188 507	43 040	29 149	768 785
Sports facility	530	39 451	177 493	210 610	217 897	1 335 250	1 003 505	1 740 745	556 705	323 538	5 605 194
Other leisure building	590	80 534	226 849	90 578	58 168	159 350	109 127	402 817	159 460	82 775	1 369 166
Total	All	31 065 524	71 938 923	42 591 412	32 351 649	85 331 141	46 371 473	68 236 428	28 471 627	17 808 164	424 166 341

Buildings without heat installations

Table 29 shows the total heated area, excluding buildings recorded as not having any heat installations, since these do not entail any potential heat saving. To illustrate the extent of this area, figure 32 shows a calculation of the residential area and commercial area with and without heat installations.

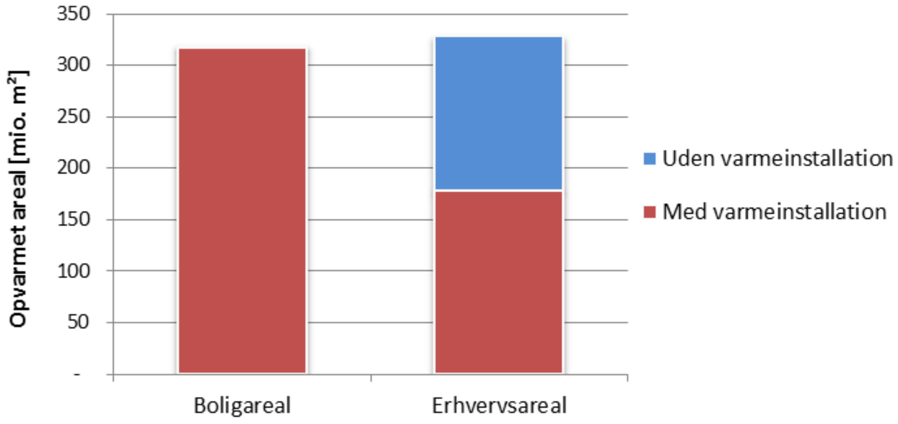

Figure 32. The heated area calculated by use for residential and commercial areas respectively and for cases where the building in question does not have any heat installations. Buildings without heat installations have been omitted from the analysis.

Danish	English
Opvarmet areal [mio. m^2]	Heated area [million m^2]
Boligareal	Residential area
Erhvervsareal	Commercial area
Uden varmeinstallation	Without any heat installation
Med varmeinstallation	With heat installation

It may be seen from figure 32 that approximately 45 % of the commercial area does not have any heat installations. The equivalent proportion of residential area is falling in relation to the total heated area.

Protected buildings and buildings worth preserving

Protected buildings and buildings worth preserving have been omitted from the analysis of potential heat savings, since energy renovations of such buildings are usually associated with major architectonic and technical construction challenges. Figure 33 shows the heated area for buildings recorded in the BBR as being protected or worth preserving, calculated by ownership.

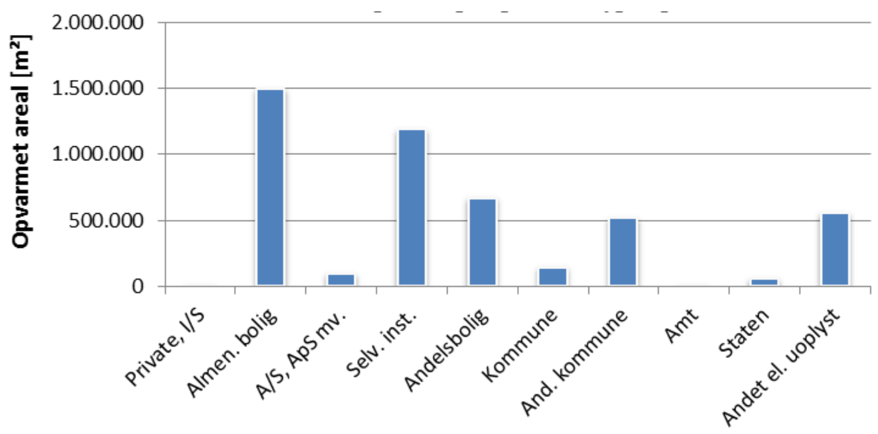

Figure 33. The heated area for buildings recorded in the BBR as being protected or worth preserving, calculated by ownership (county = region).

Danish	English
Opvarmet areal [m^2]	Heated area [m^2]
Private, I/S	Private individuals, I/S
Almen, bolig	General, homes
A/S, ApS mv.	A/S, ApS, etc.
Selv. inst.	Self-owned institutions
Andelsbolig	Part-owned homes
Kommune	Local government
And. kommune	Other local government
Amt	County council
Staten	State
Andet el. uoplyst	Other or unknown

Protected buildings and buildings worth preserving also constitute approximately 1 % of the heated area, and the proportion is greatest for general homes.

This report presents analyses with the purpose to clarify the energy savings of net heating 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. The analyses are compared with an evaluation of the effect of a 100 % compliance with the requirements as this constitutes the ultimative energy savings in combination with planned building renovation. Additionally, the effect of implementing more tight energy requirements has been analysed.

A calculation model has been established using information from the Danish building and dwelling stock register (BBR) and data from the Danish building energy certification (EPC) scheme that include information about insulation level, building component areas, i.e. roofs, external walls, floors and windows/doors, per unit area (gross heated floor area).

The report is made for the Danish Energy Agency and targeted the Danish building industry, the agency itself and political decision makers in preparation for the Danish 2014 strategy for energy renovation of buildings.

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