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UNIVERSITY OF AALBORG, COPENHAGEN

HEAT SAVINGS IN EXISTING BUILDINGS

POTENTIAL AND ECONOMY

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Heat savings in existing buildings

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Foreword

This report was commissioned by the Danish Energy Agency, which was seeking to estimate the potential heat savings amongst the existing building stock and associated investments and the profitability of these investments for building owners.

Awareness of the potential for heat savings is an important consideration in light of the Danish Government's goal of fossil-free energy supplies by 2050. Heating buildings accounts for around a third of total Danish energy consumption, and therefore saving heat is a key factor in reducing the capacity that will be required for the renewable energy supply system of the future.

The report does not present any conclusions regarding the optimal level of heat savings from a socio-economic perspective. To answer this question, it would also be necessary to perform economic analyses of the future energy supply system.

The report is accompanied by a spreadsheet in Microsoft Excel format containing the results of the heat saving calculations and investment requirements.

The report has been developed as part of the initiative entitled 'Energy efficient and intelligent buildings'. This initiative aims to promote energy efficiency and flexible energy consumption in buildings using data and digitalisation. The report may therefore also be used to illustrate opportunities to use existing large quantities of data on buildings in connection with the design of future energy efficiency measures.

Danish Building Research Institute, University of Aalborg, Copenhagen
Division of Energy Efficiency, Indoor Climate and Sustainability of Buildings
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Summary

The aim of this report is to assess the heat saving potential of the existing building stock and the investments necessary to trigger the savings potential and the private economic consequences. It is generally assumed that heat savings are achieved when buildings and parts of buildings are renovated for other reasons. Estimates have been prepared for seven energy efficiency scenarios where the building stock becomes more energy efficient following renovation.

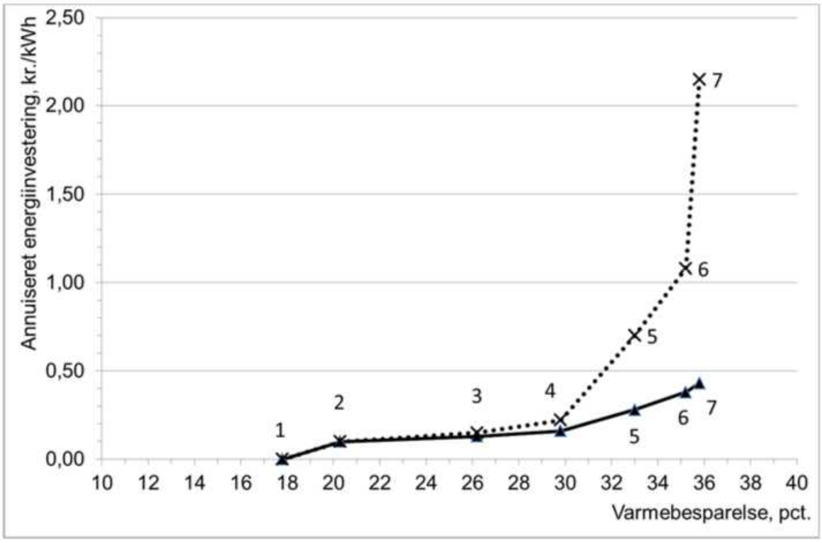
The investments associated with renovation are divided into a basic investment and an energy investment. The basic investment corresponds to the basic renovation of building elements, which means the renovated buildings specifically fulfil the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould. The energy investment represents the additional input into building elements with the primary goal of achieving heat savings.

Table 1 shows the main results for the building stock in the seven scenarios used in the report. The energy investment in DKK billion is calculated in relation to scenario 1, which corresponds to the basic renovation of building elements. The basic investment in performing the basic renovation of the building elements is DKK 727 billion. The annualised energy investment in DKK/kWh of heat savings is determined in consideration of the lifetime of the renovated building element and discounting according to socio-economic calculation principles. Scenario 5 corresponds to the fulfilment of current requirements in building regulations and therefore may be considered as a form of reference.

Table 1. Main results for the seven scenarios.

	Heat saving TWh/year	Heat saving %	Energy investment DKK billion	Annualised energy investment DKK/kWh
Scenario 1	8.8	17.8	0.0	0.00
Scenario 2	10.0	20.3	2.7	0.10
Scenario 3	12.9	26.2	10.2	0.13
Scenario 4	14.7	29.8	18.0	0.16
Scenario 5	16.3	33.0	40.6	0.28
Scenario 6	17.4	35.2	64.7	0.38
Scenario 7	17.7	35.8	76.2	0.43

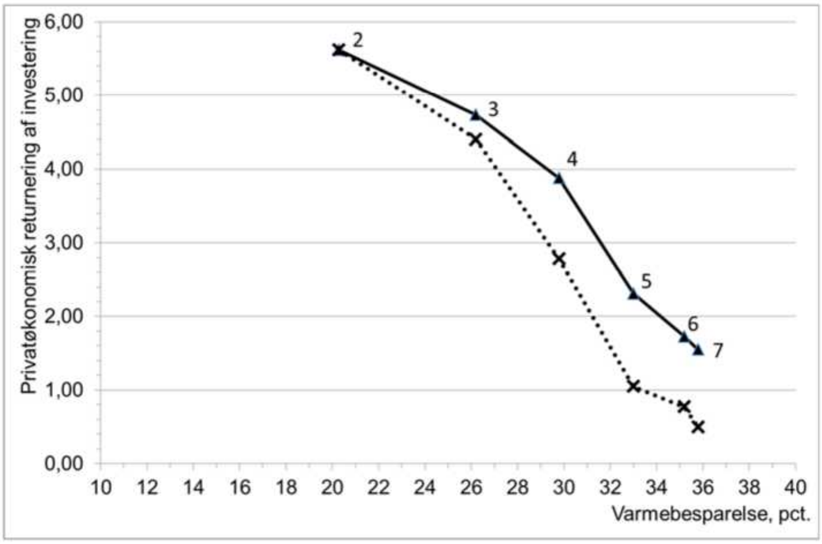
Figure 1 shows the relationship between the annualised energy investment in DKK/kWh and the magnitude of the heat saving as a percentage for the building stock. The investment is shown both as the total investment for the scenarios and as the marginal investment for the measures in the last scenario included. Around 17% of the heat saving is achieved by carrying out the basic renovation of the building elements and the current building regulation requirements are expected to give a heat saving of around 33% with a socio-economically determined annualised energy investment of DKK 0.28/kWh and a marginal annualised investment of DKK 0.70/kWh.



Annuiseret energiinvestering, kr./kWh	Annualised energy investment, DKK/kWh
Varmebesparelse, pct.	Percentage heat saving

Figure 1. Annualised energy investment in DKK/kWh depending on heat saving as a percentage. The solid line represents the total investment for the scenarios and the dashed line represents the marginal investment for the final scenario. The numbers on the graph indicate the scenario number.

Figure 2 shows the private economic return on the investment in heat savings in connection with the renovation of buildings heated using district heating or individual heat pumps. The return factor is an indication of how good the investment is. The return is calculated as both the overall economy for the scenarios and the marginal economy for the final scenario, taking into consideration factors such as energy prices, lifetimes and borrowing rates. A return factor of 1.0 means that the investment is only just repaid over the calculation period of 30 years for housing and 20 years for other buildings. If the factor is greater than 1.00, a profit will be made on the investment.



Privatøkonomisk returnering af investering	Private economic return on investment
Varmebesparelse, pct.	Percentage heat saving

Figure 2. Private economic return on investment in heat savings associated with the renovation of buildings. The solid line represents the overall return for the scenarios, while the dashed line represents the marginal return for the final scenario. The numbers on the graph indicate the scenario number.

Introduction

The aim of the report is to assess the potential heat saving of the existing building stock and the investments necessary to trigger the savings potential and the private economic consequences.

The report also builds on the methods previously used in SBi 2014:01, ‘Potential heat savings during ongoing renovations of buildings until 2050’, which is the most recent of the previous analyses of the heat saving potential in the existing Danish building stock. However, this report builds on analyses in a number of areas.

The objective is to assess the savings potential and the investments in realising this in buildings up to 2050 when there is a political objective of independence from fossil fuels. Heat savings in buildings can contribute by reducing the need for supply and thereby the need for building new supply capacity based on renewable energy and reinforcement of the infrastructure.

It is generally assumed that heat savings are achieved when buildings and parts of buildings are renovated for other reasons. This is based on the building stock that we have at present. It has not been part of the assignment to take into consideration demolitions or new builds leading up to 2050. The heat requirement of buildings is calculated as the net heat demand for space heating and hot water.

The investments for the realisation of the savings potential covers the technical costs, i.e. investments for the improvement of insulation, etc.

The analysis does not cover an assessment of the support that may need to be used to realise the potential and the associated support costs are not included in the analysis.

For private economy, which also covers the corresponding economy for companies, the objective has been both to analyse the private economic costs associated with investing in heat savings and comparing this with the cost of the corresponding energy supplied by energy supplies based on the current energy supply system. Indirect effects such as improved indoor climate and reduced environmental impacts are not included.

Buildings

The characteristics of the existing building stock have been calculated based on data in the Central Register of Buildings and Dwellings (Bygnings- og Boligregistret (BBR)) and the energy labelling scheme (Energimærkningsordningen (EMO)) database. BBR data is a copy of the BBR database as of 13 June 2016, which the Danish Energy Agency has provided for the project. The EMO data is an extract from the energy labelling scheme database generated on 23 January 2017. The EMO database contains data for 527 000 buildings, corresponding to 30% of the buildings in BBR.

Building types

The existing building stock is based on BBR and divided into six main types according to use, as shown in Table 2. Only buildings that are heated for year-round use have been included.

Table 2. Building types.

Building use	Use code in BBR
Farmhouse	110
Detached house	120
Terraced house	130
Apartment building, etc.	140, 150, 160, 190
Trade and services	320, 330, 390
Institutions	410, 420, 430, 490

Construction periods

The building types are in turn subdivided according to the building's year of construction. Table 3 shows the nine construction periods, which are characterised by either typical building style (older periods) or constraints relating to energy requirements under building regulations (more recent periods).

Table 3. Construction periods used.

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

Insulation levels

New to the existing building stock is that the buildings are also divided according to insulation of the building envelope expressed as the design transmission loss through the building envelope in W/m^2 building envelope, excluding windows and doors, as specified in Table 4. Building regulations have contained requirements concerning the design transmission loss through the building envelope, excluding windows and doors, in new builds since 2006. The requirement for new builds is currently a maximum of 4.0 W/m^2 building envelope for single storey buildings, 5.0 W/m^2 building envelope for buildings with two storeys and 6.0 W/m^2 building envelope for buildings with three or more storeys. The requirement for new builds was tightened in 2010 and again in 2015 by 1.0 W/m^2. For example, the requirement for single storey buildings up to 2010 was 6.0 W/m^2 building envelope, excluding windows and doors. The design transmission loss for the building envelope is calculated automatically in connection with the energy labelling of buildings, including existing buildings, as this is built into the core of the calculation, but is not yet included in the energy rating.
DT1 corresponds to up to approximately double the transmission loss in relation to new builds, DT2 corresponds to 2-4 times the value and DT3 is more than four times higher than in new builds.

Table 4. Division of buildings according to design transmission loss in W per m^2 building envelope, excluding windows and doors.

	DT1	DT2	DT3
Design transmission loss	<12	12<=DT<25	>=25

Heat requirement

Based on data obtained from the energy labelling scheme concerning the current insulation standard of buildings and the area of the building elements per unit area (heated floor area), a model for unit consumption is set up in each category, e.g. a detached house built during the period 1961–1972 with a design transmission loss for the building envelope with the level DT2.

Based on the average heat consumption for each category (building type, year of construction and insulation standard), the heat consumption is extrapolated for the total floor area registered in BBR for each category. The result of the total extrapolated heat consumption is compared with the Danish Energy Agency Energy Statistics 2015 to ensure the correct dimensions for the starting point before calculating the savings potential (see later in this section).

In addition to dividing the building stock according to the design transmission loss of buildings for the building envelope, the division is also used to include the effect of the estimated room temperature in the heat demand; see Table 5. This means that different degree-day figures are used for the buildings depending on the insulation class they fall under prior to retrospective insulation. This reflects the fact that the heat requirement in poorly insulated buildings is lower than expected, which is probably because a lower room temperature is maintained in the buildings because of the heating costs. However, the method does not take into account any changes in the habits of residents in connection with renovation, e.g. in terms of room temperature, ventilation and hot water consumption.

Table 5 Calculation of room temperature in °C for the various building types and design transmission loss for the building envelope.

Building type	DT1	DT2	DT3
110 - 130	21	20	19
140p	21	20	20
300p	21	20	20
400p	21	20	20

The model for the unit consumption of the categories includes heat loss through the building envelope and in connection with ventilation and heat consumption for hot water, including unusable heat losses from pipes and storage units. In addition, heating contributions are included in the form of the heat given off by people, installations consuming electricity and sunlight through windows. A degree-day method was used to assess heat consumption in the current building stock.

The calculated net heat requirement for the building stock is compared with the corresponding calculation in the Danish Energy Agency Energy Statistics 2015. For housing, this illustrates a deviation of around 1%, which is considered acceptable. For trade and services and institutions, the deviation in relation to the Energy Statistics is + 4%, which amongst other things may be due to differences or uncertainty regarding the buildings included in the calculations as well as floor areas for mixed-use buildings. Additionally, it cannot be expected that the calculated heat consumption for these buildings will be such a good fit for these building categories because there are far greater differences in patterns of use than is the case for housing. However, this does not affect the relative savings calculated.

The analyses only include net heat savings; hence, the effect of an energy upgrade or the improved operation of the building's energy supply is not included. However, an average assessment may be performed subsequently based on the net heat requirements of the renovated buildings. Any reduction in net consumption resulting from improved control and automation, etc. is not included.

Construction types
The building elements included in the study are in this context roof constructions, exterior walls, floors, windows and ventilation. The constructions in the EMO database are categorised according to construction types, see Table 6.

Numbers for constructions ending with x-x-0-0 represent a collection number, which is unspecified for the main category. In order to calculate the cost of energy upgrading, it has been necessary to assume the same distribution of this collection category as for the other categorised constructions in the same main category, e.g. roofs. There are very few or no constructions registered for certain subcategories (indicated in yellow) of constructions, which for example applies to ‘vaulted ceilings’. It is therefore assumed that ‘vaulted ceilings’ may be found under the category ‘loft’.

Table 6. Division of constructions according to construction type.

Façades	
1-2-0-0	Exterior walls
1-2-1-0	External cavity walls
1-2-2-0	Solid exterior walls
1-2-3-0	Lightweight exterior walls
1-2-1-1	Cavity walls adjoining an unheated space
1-2-2-1	Solid walls adjoining an unheated space
1-2-3-1	Lightweight walls adjoining an unheated space
1-2-4-0	Basement – exterior walls
Roof	
1-1-0-0	Roof and ceiling
1-1-1-0	Loft
1-1-2-0	Flat roof
1-1-3-0	Vaulted ceiling
Windows	
1-3-0-0	Windows, rooflights and doors
1-3-1-0	Windows
1-3-2-0	Rooflights
1 -3-3-0	External doors
Floors	
1-4-0-0	Floors
1-4-1-0	Slab
1 -4-3-0	Crawl space
1 -4-4-0	Basement floor
1-4-1-1	Slab with underfloor heating
1-4-3-1	Crawl space with underfloor heating

Table 7 provides an example of the U-values for heavy exterior walls in a detached house built in the period 1931–50. The calculation shown is for solid exterior walls (No 1-2-2-0) and external cavity walls (No 1-2-1-0) and calculated according to the three insulation conditions for the buildings DT1, DT2 and DT3. It can be seen for example that 93% of the cavity wall area in a house with the insulation standard DT1 has a U-value that is 0.70 W/K m² or better, while only 36% of the cavity wall area in a house with insulation standard DT3, has a U-value of 0.70 W/K m² or better. Similarly, it can be seen that only 38% of the exterior wall area in a house with solid exterior walls and an insulation standard of DT3 has a U-value that is 1.20 W/K m² or better.

Table 7. Accumulated distribution of U-values for heavy exterior walls in detached houses (120) built during the period 1931-50 (p3).

U-value	Solid exterior walls			Cavity walls		
W/K m2	DT1	DT2	DT3	DT1	DT2	DT3
0.05	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.00	0.00	0.00	0.00	0.00
0.15	0.03	0.00	0.00	0.01	0.00	0.00
0.20	0.15	0.02	0.01	0.07	0.01	0.00
0.25	0.29	0.06	0.01	0.17	0.03	0.01
0.30	0.46	0.11	0.02	0.34	0.08	0.02
0.35	0.65	0.20	0.05	0.39	0.09	0.02
0.40	0.80	0.31	0.08	0.48	0.15	0.05
0.45	0.82	0.34	0.09	0.62	0.29	0.12
0.50	0.87	0.40	0.10	0.71	0.35	0.14
0.55	0.89	0.43	0.12	0.75	0.41	0.17
0.60	0.91	0.49	0.15	0.83	0.53	0.22
0.65	0.92	0.53	0.17	0.84	0.56	0.24
0.70	0.94	0.56	0.19	0.93	0.75	0.36
0.75	0.95	0.60	0.21	0.95	0.78	0.38
0.80	0.96	0.62	0.21	0.97	0.91	0.47
0.85	0.96	0.63	0.23	0.97	0.91	0.47
0.90	0.96	0.66	0.24	0.98	0.93	0.51
0.95	0.96	0.68	0.25	0.98	0.94	0.52
1.00	0.96	0.71	0.28	0.98	0.95	0.54
1.05	0.97	0.71	0.29	0.98	0.95	0.54
1.10	0.97	0.75	0.34	0.98	0.95	0.54
1.15	0.97	0.75	0.35	0.98	0.95	0.54
1.20	0.98	0.77	0.38	0.98	0.95	0.56
1.25	0.98	0.77	0.40	0.98	0.96	0.56
1.30	0.98	0.78	0.42	0.98	0.96	0.57
1.35	0.98	0.79	0.46	0.99	0.96	0.59
1.40	0.98	0.80	0.47	0.99	0.96	0.60
1.45	0.98	0.80	0.48	0.99	0.96	0.60
1.50	0.98	0.82	0.56	0.99	0.98	0.71

Building data

Table 8 shows the main data for the existing building stock as it is today at the starting point.

Table 8. Main data for the existing building stock. Number of buildings, floor area of building stock in Mm^2, current net heat consumption in TWh/year and net heat consumption per m^2 floor area in kWh/year per m^2 and the design heat output in MW.

	Buildings	Mm^2	TWh/year	kWh/year per m^2	MW
Farmhouse	113,980	22.0	2.77	126	1,115
Detached house	1,102,462	162.2	20.50	126	8,015
Terraced house	244,885	37.1	4.05	109	1,532
Apartment building, etc.	102,558	92.3	10.36	112	4,040
Trade and services	109,180	84.4	7.72	91	3,868
Institutions	44,515	38.3	3.97	104	1,969
Total	1,717,580	436.3	49.37	113	20,539

Table 9 shows the floor area divided according to building type and construction period. The colour in the table changes from green for a large number of figures to red for a small number of figures. It can be seen that the largest building area relates to detached houses built during the period 1960-72. However, there are also large building areas for detached houses built during the period 1890-1929 and 1973-98, in apartment buildings from 1890-1929 and in institutions from 1979-98.

Table 9. Floor area divided by building type and construction period.

Gross area	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
m^{2*}1000	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110	6,544	8,643	2,376	749	858	628	968	464	733	**21,964**
120	10,467	25,948	16,846	12,018	40,852	22,254	17,965	7,508	8,351	**162,208**
130	1,529	2,434	1,790	2,218	4,910	3,763	12,962	4,135	3,391	**37,130**
140	6,276	21,491	15,533	8,529	16,585	5,348	9,157	4,540	4,852	**92,312**
300	4,671	8,809	4,225	3,878	14,721	7,630	20,230	9,771	10,465	**84,399**
400	2,564	4,566	2,683	3,545	8,952	4,436	6,597	2,562	2,359	**38,264**
All	**32,050**	**71,890**	**43,453**	**30,937**	**86,877**	**44,058**	**67,879**	**28,981**	**30,151**	**436,277**

Table 10 shows the floor area divided according to three insulation standards for the building envelope, calculated separately for each building type and construction period. It can be seen that the majority of the buildings built before 1973 are of insulation standard DT2 and DT3. The pink fields are combinations of building types, construction periods and insulation standards where there are no buildings. The yellow fields are corresponding combinations where there are very few buildings and a small floor area.

Table 10. Distribution of insulation standard depending on building type and construction period.

% DT1,2,3	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
m^{2*}1000	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	29.3	25.3	21.0	16.0	26.6	54.2	91.4	97.0	100.0	**33.5**
110DT2	43.5	47.7	52.0	55.6	66.1	45.5	8.0	3.0	0.0	**43.6**
110DT3	27.1	27.0	27.0	28.4	7.3	0.3	0.6	0.0	0.0	**22.9**
120DT1	33.7	19.6	12.0	12.0	34.1	61.5	93.3	99.4	99.5	**44.5**
120DT2	46.9	52.9	59.5	65.5	62.6	38.2	6.6	0.5	0.5	**44.3**
120DT3	19.5	27.5	28.4	22.6	3.4	0.3	0.1	0.0	0.1	**11.2**
130DT1	25.4	16.9	8.0	11.1	36.2	51.9	96.1	99.5	99.3	**67.0**
130DT2	43.1	44.3	53.7	64.8	53.7	44.6	3.6	0.4	0.0	**24.1**
130DT3	31.5	38.8	38.3	24.1	10.1	3.5	0.3	0.1	0.7	**9.0**
140pDT1	6.1	4.7	4.0	9.8	19.1	35.0	83.2	96.0	98.2	**26.7**
140pDT2	30.3	23.3	20.3	34.2	59.2	56.6	16.4	3.9	1.3	**29.9**
140pDT3	63.6	72.0	75.7	56.0	21.7	8.4	0.4	0.0	0.5	**43.5**
300pDT1	12.9	13.0	19.1	15.8	30.5	38.7	80.4	91.7	93.3	**54.0**
300pDT2	36.7	39.4	35.9	51.7	56.9	56.4	18.4	7.5	2.9	**31.0**
300pDT3	50.4	47.7	45.0	32.5	12.6	4.9	1.2	0.8	3.8	**15.0**
400pDT1	9.8	11.3	16.9	15.9	28.5	48.8	89.2	95.6	98.9	**44.8**
400pDT2	50.5	49.1	52.2	69.1	64.0	46.3	10.4	4.3	1.1	**41.8**
400pDT3	39.7	39.6	30.9	15.1	7.5	5.0	0.4	0.1	0.0	**13.4**
All	**7.3**	**16.5**	**10.0**	**7.1**	**19.9**	**10.1**	**15.6**	**6.6**	**6.9**	**100.0**

Table 11 shows the total calculated heat requirement for the various building types, construction periods and insulation standards. Combinations with a large floor area weigh heavily for the total heat requirement, particularly in combination with older construction periods or poorer insulation standards.

Table 11. Total calculated heat requirement for the various building types, construction periods and insulation standards. (The asis in the table head indicates the starting point of the base situation)

Asis	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
TWh	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	0.203	0.232	0.053	0.013	0.026	0.039	0.095	0.041	0.056	**0.758**
110DT2	0.367	0.502	0.146	0.050	0.070	0.033	0.008	0.001	0.000	**1.177**
110DT3	0.320	0.381	0.095	0.033	0.009	0.000	0.001	0.000	0.000	**0.840**
120DT1	0.387	0.568	0.236	0.174	1.808	1.729	1.919	0.713	0.658	**8.193**
120DT2	0.626	1.722	1.292	1.090	3.433	1.055	0.139	0.004	0.004	**9.365**
120DT3	0.361	1.141	0.763	0.451	0.214	0.009	0.003	0.000	0.000	**2.941**
130DT1	0.039	0.042	0.015	0.028	0.203	0.235	1.374	0.392	0.269	**2.598**
130DT2	0.075	0.121	0.112	0.168	0.316	0.190	0.049	0.002	0.000	**1.033**
130DT3	0.066	0.127	0.087	0.070	0.053	0.009	0.004	0.000	0.001	**0.417**
140pDT1	0.040	0.110	0.078	0.089	0.319	0.189	0.819	0.464	0.418	**2.527**
140pDT2	0.218	0.582	0.360	0.315	0.980	0.298	0.147	0.016	0.005	**2.920**
140pDT3	0.484	1.943	1.459	0.570	0.401	0.049	0.005	0.000	0.001	**4.911**
300pDT1	0.060	0.111	0.081	0.068	0.458	0.306	1.560	0.687	0.729	**4.060**
300pDT2	0.176	0.340	0.146	0.192	0.761	0.396	0.287	0.042	0.021	**2.360**
300pDT3	0.257	0.450	0.213	0.129	0.178	0.034	0.023	0.002	0.012	**1.298**
400pDT1	0.031	0.060	0.054	0.065	0.295	0.224	0.601	0.218	0.182	**1.731**
400pDT2	0.149	0.245	0.152	0.261	0.580	0.181	0.061	0.007	0.001	**1.638**
400pDT3	0.128	0.216	0.103	0.070	0.064	0.017	0.003	0.000	0.000	**0.600**
All	**3.984**	**8.895**	**5.445**	**3.837**	**10.168**	**4.994**	**7.097**	**2.590**	**2.357**	**49.368**

Table 12 illustrates the calculated heat requirement per m^2 floor area for the various building types, construction periods and insulation standards. Combinations with very small floor areas have been omitted from the table. Some of the values for apartment buildings, trade and services and institutions with the insulation standard DT2 and DT3 built after 1960 appear to be something of a mystery because they are lower than for insulation standard DT1. This may be due to factors such as mechanical ventilation, variation in window area, few buildings in the categories, uncertainty regarding the actual use of the building or errors in the dataset. It has not been possible to establish the actual reason for this or make valid corrections.

Table 12. Calculated heat requirement per m floor area for the various building types, construction periods and insulation standards.

Asis	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
kWh/m^2	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	105.5	106.3	106.9	107.8	115.6	115.2	106.9	91.0	75.7	**102.9**
110DT2	128.8	121.6	118.3	119.4	123.1	116.6	104.3			**123.0**
110DT3	180.0	163.6	148.1	156.2	147.7					**166.9**
120DT1	109.7	111.7	116.4	121.4	129.9	126.4	114.5	95.5	79.2	**113.5**
120DT2	127.6	125.5	128.8	138.6	134.3	124.1	116.7			**130.3**
120DT3	177.2	160.0	159.3	166.1						**162.1**
130DT1	99.8	101.4	107.3	114.2	114.2	120.4	110.3	95.3	80.0	**104.5**
130DT2	114.3	112.5	116.2	117.2	120.0	113.1				**115.7**
130DT3	136.0	134.8	126.9	130.9	107.7					**125.0**
140pDT1	104.0			106.2	100.8	101.1	107.6	106.4	87.8	**102.6**
140pDT2	114.7	116.0	114.0	108.0	99.8	98.5	98.1			**105.9**
140pDT3	121.3	125.6	124.1	119.3	111.2	108.9				**122.4**
300pDT1	99.8	97.1	100.7	109.9	102.0	103.7	95.9	76.7	74.7	**89.0**
300pDT2	102.8	98.1	96.3	95.7	90.8	91.9	77.1	57.1		**90.3**
300pDT3	109.2	107.1	111.8	102.7	95.8					**102.7**
400pDT1	121.0	117.0	119.3	116.2	115.7	103.8	102.1	88.9	78.1	**100.8**
400pDT2	114.9	109.4	108.8	106.6	101.3	88.0	89.5			**102.5**
400pDT3	125.9	119.3	124.2	131.5	94.5					**117.4**
All	**124.3**	**123.7**	**125.3**	**124.0**	**117.0**	**113.4**	**104.6**	**89.4**	**78.2**	**113.2**

Table 13 correspondingly illustrates the design heat output per m^2 floor area for the various building types, construction periods and insulation standards. The values for these are in the order expected for the insulation standards DT1, DT2 and DT3.

Table 13. Design heat output per m^2 floor area for the various building types, construction periods and insulation standards.

Designed	p1	p2	p3	p4	p5	p6	p7	p8	p9	PS
W/m^2	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	36	37	37	37	40	40	37	32	28	**36**
110DT2	51	49	48	48	50	48	44			**49**
110DT3	80	74	69	72	70					**75**
120DT1	38	39	40	42	45	44	40	34	29	**40**
120DT2	51	50	52	56	55	51	48			**53**
120DT3	79	73	74	77						**75**
130DT1	34	35	37	39	40	42	38	34	29	**36**
130DT2	46	45	47	48	50	48				**48**
130DT3	64	63	61	64	57					**61**
140pDT1	33			34	33	33	34	35	29	**33**
140pDT2	43	44	43	42	40	39	38			**41**
140pDT3	51	53	52	52	50	49				**52**
300pDT1	42	41	43	46	43	43	41	36	35	**39**
300pDT2	54	52	52	52	50	50	45	40		**50**
300pDT3	64	63	65	63	59					**61**
400pDT1	49	48	49	48	49	45	44	41	36	**44**
400pDT2	58	57	57	56	55	50	51			**55**
400pDT3	69	67	69	72	61					**67**
All	**53**	**53**	**54**	**54**	**49**	**46**	**40**	**35**	**32**	**47**

Energy efficiency scenarios

Estimates have been prepared for seven energy efficiency scenarios where the building stock becomes increasingly more energy efficient following renovation. The scenarios are arranged in order so as to contain the most cost-effective measures first in the scenarios with the lowest numbers. Measures included will not be removed again in scenarios with higher numbers, but may in some cases be expanded, e.g. with more insulation. An overview of the scenarios is shown in Table 14.

Table 14. Overview of the energy efficiency scenarios.

Number	Scenario
0	Starting point without measures
1	Minimum in connection with basic renovation of building components to an acceptable building technical standard
2	Scenario 1 + Insulation of empty cavity walls
3	Scenario 2 + Windows with energy rating A
4	Scenario 3 + Some loft and ceiling insulation
5	Usual good practice for insulation in connection with renovation
6	Energy focus in connection with insulation of renovated building elements
7	Scenario 6 + retrospective insulation of the loft and roof corresponding to scenario 6

Scenario 1 corresponds to the basic renovation of building elements to fulfil the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould. The measures to fulfil this depend on the building element and construction.

For light constructions, it is assumed that there will be a minimum of 75 mm of insulation in the construction for this to be of an acceptable building technical standard and to avoid comfort problems or internal moisture and mould on the constructions or on the wind protection and under-roof area. The 75 mm corresponds to a structure with 25 mm insulation, vapour barrier and 50 mm insulation outside the vapour barrier. The innermost 25 mm insulation ensures that the vapour barrier is not penetrated by existing or new nails and screws in the internal cladding. The outermost 50 mm of insulation ensures that internal surface of the vapour barrier does not become so cold that condensation builds up on it under normal conditions.

For heavy exterior walls, it is assumed that the U-value should preferably be better than 1.0 - 1.5 W/K m^2 so as to be reasonably certain there will be no comfort or condensation problems, including mould behind furniture and in bathrooms. This can be achieved with 25 mm external insulation with a single course brick wall, for example.

In the case of windows, it is not possible to purchase windows with an energy rating worse than B. The reference for windows therefore is a window with energy rating B.

It is also assumed that 10% of the floor area where there is no mechanical ventilation will be supplied with mechanical ventilation with heat recovery to achieve a better indoor climate.

Table 15 provides an overview of the insulation levels of the various scenarios. Insulation thicknesses for typical insulation products and constructions.

The anticipated execution of renovation of individual building elements leading up to 2050 is shown in Table 16 and is the same for a given measure in all scenarios where this is included.

Scenario 2 is the same as scenario 1, but is expanded to include filling cavity walls with insulation.

Table 15. Overview of measures in the scenarios. Only scenarios in which new measures are taken in relation to previous measures in scenarios with a lower number are included in the list.

Building element	Scenario	Measures	U-value W/K m^2
Façades			
External cavity walls	1	None	-
	2	To be completed	0.70
Solid exterior walls	1	25 mm if poor	1.20
	5	125 mm if poor	0.35
Lightweight exterior walls	1	75 mm	0.50
	5	100 mm	0.40
Basement exterior walls	1	None	-
	5	100 mm	0.30
Roof			
Loft	1	75 mm	0.45
	4	200 mm	0.20
	5	250 mm	0.15
	6	350 mm	0.10
Flat roof	1	100 mm	0.45
	4	150 mm	0.25
	5	200 mm	0.20
	6	300 mm	0.15
Windows	1	Energy rating B	1.30
	3	Energy rating A	0.90
Floors			
Slab	1	100 mm (equivalent)	0.20
	5	200 mm	0.15
	6	300 mm	0.10
Crawl space slab	1	75 mm	0.45
	5	150 mm	0.25
	6	200 mm	0.20
Basement floor	1	100 mm (equivalent)	0.20
	5	200 mm	0.15
	6	300 mm	0.10
Heated slab	1	100 mm (equivalent)	0.20
	5	200 mm	0.15
	6	300 mm	0.10
Heated crawl space slab	1	75 mm	0.45
	5	150 mm	0.25
	6	200 mm	0.20

Similarly, scenario 3 is the same as scenario 2, but with the windows upgraded from energy rating B to energy rating A. It is anticipated energy rating A will become a requirement from 2020; see Danish Building Regulations 2015.

Scenario 4 builds on scenario 3 by adding more insulation on the roof, as specified in more detail in Table 15. This roof insulation is typically slightly less than would normally be used in connection with the renovation of a roof today.

Scenario 5 corresponds to good practice for the insulation level for the renovation of building elements, taking into consideration building regulation requirements, existing construction heights and the scope offered by building regulations to reduce insulation thicknesses according to the profitability of retrospective insulation. The determination of the insulation values has taken into account the fact that these cover a wide variety of structures, including the fact that ceiling insulation may for example cover vaulted ceilings (parallel ceilings), where there is less space for insulation than in the case of a ceiling in an open loft space For example, it is assumed that all ceilings that do not have 250 mm insulation will be insulated to achieve a total of 250 mm of insulation. The scenario does not take into consideration the fact that renovations are not always performed according to good practice in relation to insulation.

Scenario 6 involves large insulation thicknesses in the constructions where there is an increase in the insulation thickness in relation to scenario 5. For example, this means that it is assumed that for ceilings that do not have 250 mm of insulation, insulation will be added to a thickness of 350 mm, which under scenario 5 would only need to be insulated to 250 mm. This also means that this scenario does not involve the additional insulation of ceilings that are already insulated to 250 mm.

Table 16. Overview of percentage implementation rates up to 2050

Building element	Implementation rate	Remarks
Façades		
External cavity walls	100	
Solid exterior walls	50	Of walls worse than 1.50 W/K m^2 e.g. in concrete and single course brick walls without insulation
Lightweight exterior walls	100	
Basement exterior walls	30	Of walls worse than 0.70 W/K m^2 e.g. in concrete without insulation
Roof		
Loft	100	
Flat roof	100	
Windows		
Windows	100	
Rooflights	100	
External doors	100	
Windows, general	100	
Floors		
Slab	30	For slab with values worse than 0.30 W/K m^2, e.g. 20 cm expanded clay aggregate (50 mm insulation equivalent)
Crawl space slab	100	
Basement floor	10	For basement floors with values worse than 0.40 W/K m^2, e.g. 20 cm expanded clay aggregate (50 mm insulation equivalent)
Heated slab	30	For slab with values worse than 0.25 W/K m^2, e.g. 30 cm expanded clay aggregate (75 mm insulation equivalent)
Heated crawl space slab	100	

Scenario 7 expands the scope of constructions given retrospective insulation, as all constructions that are not at the final level of insulation are retrospectively insulated to the final value in scenario 6. For example, this means that ceilings with 250-350 mm insulation are retrospectively insulated to 350 mm.

The general basis is that renovation is triggered by the condition of the building elements and not how well insulated they are. For example, it is assumed that a roof will be replaced when it is no longer watertight or close to no longer being watertight, and windows will be replaced when they are rotten or otherwise degraded.

The implementation rates must be viewed in the context of the measures in Table 15 and the lifetimes following renovation in Table 34. For example, this stipulates that the implementation rate is 100% for cavity walls and in Table 15 it states as a measure under scenario 1 that nothing is to be done with cavity walls. This results in nothing being done with cavity walls under scenario 1. This is in turn done under scenario 2, where it is assumed that all cavity walls that have not already been filled with insulation will be filled with insulation by 2050.

The implementation rate is 50% for solid exterior walls; however, only for solid exterior walls with a U-value worse than 1.50 W/K m^2, which corresponds to solid exterior walls in concrete or single course brick walls without insulation. This means that it is assumed that only half of the solid exterior walls anticipated to give indoor climate problems will be retrospectively insulated. The reason for this may for example be because of a desire or requirement to preserve the façade of the building.

The implementation rate is 100% for lightweight exterior walls. This means that in scenario 1, all lightweight exterior walls with a U-value worse than 0.50 W/K m^2 (corresponding to insulation of around 75 mm) will be insulated to a U-value of 0.50 W/K m^2 before 2050 in connection with the renovation of external walls for other reasons. The principle is the same in scenario 5, except that only all lightweight exterior walls with a U-value worse than 0.40 W/K m^2 (corresponding to around 100 mm of insulation) will be insulated to a U-value of 0.40 W/K m^2 by 2050. It will in many cases be difficult to achieve more than 100 mm of insulation in the existing construction unless it is already there because of the amount of existing space.

The principle described for the three examples above will be used for all of the building elements in Table 15 and Table 16.

The implementation rates are maintained across the scenarios because these are fundamentally derived from an assessment of the need for renovation and not based on a desire for energy savings. Thus, essentially the same building elements are being renovated in all of the scenarios. Only the degree of energy savings increases across the scenarios.

The implementation rate has been set at 100% for roofs and windows because their expected lifetime means that it is anticipated that these would need to be renovated by 2050. However, there may be a small percentage of roofs that will not require renovation until the start of the 2050s.

The implementation rate is generally low for the slab and basement floors because there must be a particularly good reason for breaking these up during renovation, as this is both inconvenient and expensive. Therefore, this will typically only happen when repairing damaged pipes or installing underfloor heating.

Savings potential

Table 17 shows the reduction in the heat requirement associated with the various scenarios, and Table 18 shows the relative reduction in relation to the present starting point. For example, the 33% reduction in scenario 5 corresponds to a reduction of the average heat requirement in the building stock from 113 kWh/year m^2 to 76 kWh/year m^2.

It is initially assumed in scenario 1 that mechanical ventilation will be installed for 10% of the floor area that currently has natural ventilation to improve the indoor climate. A 10% increase in the use of mechanical ventilation with heat recovery reduces the heat requirement by 1.1% or 0.54 TWh/year. For example, if the use of mechanical ventilation instead corresponds to 30% of the floor area because of the indoor climate, the total reduction in scenario 5 will instead be 35.2% and the average heat requirement in the building stock will be reduced to 73 kWh/year m^2.

Table 17. Reduction in heat requirement in TWh/year for the various scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	0.58	0.71	0.85	1.01	1.12	1.20	1.21
Detached house	3.46	4.06	5.21	6.12	6.88	7.43	7.56
Terraced house	0.69	0.74	1.00	1.11	1.27	1.38	1.41
Apartment building, etc.	1.89	2.18	2.79	3.01	3.22	3.33	3.36
Trade and services	1.43	1.53	2.00	2.24	2.46	2.63	2.67
Institutions	0.76	0.83	1.07	1.21	1.34	1.43	1.46
Total	8.81	10.04	12.92	14.70	16.28	17.40	17.67

Table 18. Relative reduction in the percentage heat requirement for the various scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	21.0	25.8	30.5	36.2	40.3	43.1	43.5
Detached house	16.9	19.8	25.4	29.9	33.5	36.2	36.9
Terraced house	17.0	18.2	24.7	27.5	31.3	34.1	34.9
Apartment building, etc.	18.2	21.0	26.9	29.1	31.1	32.2	32.4
Trade and services	18.5	19.8	25.9	29.0	31.9	34.0	34.6
Institutions	19.2	20.9	26.9	30.5	33.7	36.0	36.7
Total	17.8	20.3	26.2	29.8	33.0	35.2	35.8

Table 19 and Table 20 similarly show the reduction in the design heat output for the various scenarios and the relative reduction in relation to the present starting point. The future increase in the use of mechanical ventilation also affects the design heat output. A 10% increase in the use of mechanical ventilation with heat recovery reduces the design heat output by 0.9% or 178 MW.

Table 19. Reduction in design heat output in MW for the various scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	213	260	304	359	398	424	428
Detached house	1,240	1,453	1,832	2,139	2,392	2,575	2,617
Terraced house	239	257	342	380	431	468	478
Apartment building, etc.	693	791	994	1,068	1,137	1,175	1,183
Trade and services	495	528	681	761	834	887	901
Institutions	266	289	366	413	456	486	494
Total	3,147	3,577	4,519	5,120	5,648	6,015	6,101

Table 20. Relative reduction in the percentage design heat output for the various scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	19.1	23.3	27.3	32.2	35.7	38.0	38.4
Detached house	15.5	18.1	22.9	26.7	29.8	32.1	32.7
Terraced house	15.6	16.7	22.3	24.8	28.1	30.6	31.2
Apartment building, etc.	17.2	19.6	24.6	26.4	28.1	29.1	29.3
Trade and services	12.8	13.6	17.6	19.7	21.6	22.9	23.3
Institutions	13.5	14.7	18.6	21.0	23.2	24.7	25.1
Total	15.3	17.4	22.0	24.9	27.5	29.3	29.7

Scenario 5

The results for scenario 5 are shown in more detail in this section as an example of the calculations performed. More detailed results have specifically been presented for scenario 5 because scenario 5 corresponds to the fulfilment of the current requirements in building regulations (both BR15 and BR18) and may be considered as a form of reference.

Table 21 illustrates the calculated heat requirement per m² floor area for the various building types, construction periods and insulation standards following renovation.

Table 21. Calculated heat requirement per m² floor area for the various building types, construction periods and insulation standards following renovation. Scenario 5

Renovated	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
kWh/m²	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	78.5	79.5	80.5	81.6	84.6	82.6	76.7	71.7	60.0	**76.9**
110DT2	82.0	76.9	75.1	76.2	78.2	72.7	68.1			**78.0**
110DT3	75.7	65.7	60.1	63.0	61.8					**68.3**
120DT1	80.9	83.6	88.2	92.6	94.7	90.7	84.5	76.5	64.9	**84.6**
120DT2	82.6	82.3	87.6	93.7	87.1	80.2	78.7			**85.7**
120DT3	79.7	72.2	74.8	79.9						**74.8**
130DT1	71.5	74.2	80.8	83.2	81.6	82.2	80.3	76.2	65.0	**77.6**
130DT2	72.7	72.3	76.7	74.4	73.6	69.5				**73.0**
130DT3	65.8	63.3	65.1	60.2	50.0					**60.3**
140pDT1	79.0			77.4	72.7	73.5	80.8	86.3	70.1	**78.4**
140pDT2	86.0	86.1	85.2	75.5	66.0	63.9	70.4			**74.2**
140pDT3	82.4	82.2	80.0	76.0	63.4	58.8				**78.8**
300pDT1	76.4	76.1	76.5	77.6	74.7	77.0	71.2	59.5	60.6	**67.7**
300pDT2	73.3	68.5	62.3	59.4	54.8	56.5	48.1	36.4		**57.3**
300pDT3	64.0	58.6	53.1	46.2	39.5					**52.9**
400pDT1	94.1	89.4	87.7	86.9	83.7	75.2	74.8	67.1	59.3	**74.4**
400pDT2	83.9	75.7	71.4	66.4	60.4	51.5	53.4			**64.7**
400pDT3	75.6	67.9	60.3	58.2	41.6					**62.3**
All	**79.0**	**77.6**	**79.0**	**78.1**	**76.4**	**76.7**	**76.2**	**70.4**	**62.9**	**75.8**

Table 22 correspondingly shows the reduction in heat requirement following renovation.

Table 22. Reduction in heat requirement associated with renovation for the various building types, construction periods and insulation standards. Scenario 5

Saving	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
%	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	25.6	25.2	24.7	24.3	26.8	28.3	28.2	21.2	20.8	**25.3**
110DT2	36.3	36.8	36.6	36.2	36.5	37.6	34.8			**36.6**
110DT3	57.9	59.8	59.4	59.7	58.1					**59.1**
120DT1	26.2	25.2	24.2	23.7	27.1	28.2	26.2	19.9	18.1	**25.5**
120DT2	35.2	34.4	32.0	32.4	35.2	35.3	32.5			**34.2**
120DT3	55.0	54.9	53.0	51.9						**53.9**
130DT1	28.4	26.8	24.7	27.2	28.5	31.7	27.2	20.1	18.7	**25.8**
130DT2	36.4	35.7	34.0	36.5	38.6	38.6				**36.9**
130DT3	51.6	53.0	48.7	54.0	53.6					**51.8**
140pDT1	24.0			27.1	27.9	27.2	24.9	18.9	20.1	**23.6**
140pDT2	25.0	25.7	25.3	30.1	33.9	35.1	28.3			**29.9**
140pDT3	32.1	34.5	35.5	36.3	43.0	46.0				**35.6**
300pDT1	23.5	21.6	24.0	29.4	26.8	25.8	25.7	22.3	18.8	**23.9**
300pDT2	28.7	30.2	35.3	37.9	39.6	38.5	37.7	36.2		**36.6**
300pDT3	41.4	45.3	52.5	55.0	58.8					**48.5**
400pDT1	22.2	23.6	26.5	25.2	27.7	27.6	26.8	24.6	24.1	**26.2**
400pDT2	26.9	30.8	34.4	37.7	40.3	41.5	40.4			**36.9**
400pDT3	39.9	43.1	51.4	55.8	56.0					**46.9**
All	**36.4**	**37.3**	**37.0**	**37.0**	**34.7**	**32.3**	**27.2**	**21.2**	**19.5**	**33.0**

Table 23 illustrates the design heat output per m^2 floor area for the various building types, construction periods and insulation standards following renovation. It can be seen that the design heat output is reduced considerably in DT3 buildings.

Table 23. Design heat output per m^2 floor area for the various building types, construction periods and insulation standards following renovation. Scenario 5

Designed	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
W/m^2	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	28	28	28	29	30	30	28	26	23	**27**
110DT2	35	33	33	33	34	33	31			**34**
110DT3	41	37	35	37	37					**38**
120DT1	28	29	31	33	34	33	30	28	25	**30**
120DT2	35	35	37	40	38	36	35			**37**
120DT3	42	40	42	44						**41**
130DT1	25	26	28	30	29	30	28	28	24	**28**
130DT2	32	31	33	33	33	32				**33**
130DT3	37	36	38	37	34					**36**
140pDT1	25			25	24	24	25	28	24	**25**
140pDT2	33	33	33	30	28	27	28			**30**
140pDT3	37	37	36	36	32	31				**36**
300pDT1	35	35	35	36	34	35	33	30	31	**32**
300pDT2	44	42	40	40	38	38	35	33		**38**
300pDT3	47	45	44	43	39					**44**
400pDT1	41	39	39	39	38	35	35	34	32	**35**
400pDT2	47	45	44	42	41	37	38			**42**
400pDT3	51	49	47	46	42					**47**
All	**37**	**37**	**37**	**38**	**35**	**33**	**31**	**29**	**27**	**34**

Investment requirements

The calculation of the energy efficiency investments associated with renovation of the buildings is based on a separate memorandum to the Danish Energy Agency concerning 'Unit prices for calculating costs in connection with heat savings' prepared by NIRAS, March 2017.

Table 24 provides an overview of the implementation of unit prices in the calculations shown for scenario 5. The unit prices used are an average for the various building types and construction details. The basic investment corresponds to the basic renovation of building elements in scenario 1, which means the renovated building specifically fulfils the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould. The basic investment is calculated for the specific building elements and excludes construction site and scaffolding costs, etc. Any restoration of the basic structure such as the erection of load-bearing structures or the replacement of defective insulation is also not included in the investment.

The energy investment represents the additional input into building elements with the primary goal of achieving heat savings. However, this will also improve the level of comfort in the building, a factor which is not taken into account in the calculations. The energy investment is assumed to be approximately linearly proportional to the thickness of insulation. This is based on the existing insulation in the constructions.

Table 24. Basic investment and energy investment in DKK/m2 building element, excluding VAT. Scenario 5

Building element	Basis	Energy
Façades		
External cavity walls	0	175
Solid exterior walls	1,350	470
Lightweight exterior walls	1,100	50
Basement exterior walls	2,200	300
Roof		
Loft	1,200	125
Flat roof	1,000	75
Windows		
Windows	4,500	100
Rooflights	4,500	100
External doors	4,500	100
Windows, general	4,500	100
Floors		
Slab	1,700	100
Crawl space	175	75
Basement floor	1,700	100
Heated slab	2,700	75
Heated crawl space	175	75

Table 25 shows the basic investment up until 2050 in DKK million for performing the basic renovation of building elements important for energy.

Table 25. Basic investment up in DKK million for performing the basic renovation of building elements important for energy.

	DKK million
Farmhouse	40,755
Detached house	323,972
Terraced house	70,048
Apartment building, etc.	115,830
Trade and services	114,328
Institutions	61,672
Total	726,605

Table 26 shows the basic investment in DKK million divided according to building type, construction period and insulation standard. Table 27 shows the same information calculated per m² floor area.

Table 26. Basic investment in DKK million divided according to building type, construction period and insulation standard.

Basic invest.	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK million	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	3.340,4	3.723,2	844,0	206,4	432,5	651,2	1.611,5	787,9	1.140,1	**12.737,2**
110DT2	5.467,1	7.577,7	2.215,3	764,3	1.155,3	591,0	153,0	25,3	0,0	**17.949,1**
110DT3	3.732,3	4.573,3	1.200,6	411,8	133,1	4,6	13,3	0,0	0,0	**10.069,0**
120DT1	6.103,8	8.515,6	3.381,7	2.606,9	29.036,6	28.946,6	33.059,7	14.443,9	13.004,6	**139.099,3**
120DT2	9.356,5	24.579,6	18.140,9	15.740,9	58.516,1	19.628,7	2.588,2	84,1	72,6	**148.707,6**
120DT3	4.314,2	13.525,6	9.104,2	5.700,9	3.301,0	159,1	40,8	3,6	15,8	**36.165,2**
130DT1	612,5	641,1	229,4	453,9	3.272,8	3.764,9	22.879,9	8.018,2	5.458,5	**45.331,2**
130DT2	1.152,6	1.830,8	1.719,5	2.954,3	5.780,2	3.734,3	905,6	39,3	1,2	**18.117,8**
130DT3	922,1	1.729,5	1.281,7	1.130,1	1.172,9	262,9	76,8	5,4	17,1	**6.598,5**
140pDT1	429,3	1.130,9	714,0	1.051,3	4.026,4	2.349,7	9.543,1	6.059,7	5.912,3	**31.216,6**
140pDT2	2.202,6	5.858,4	3.700,7	3.650,9	13.320,5	4.253,2	1.968,3	248,8	81,0	**35.284,5**
140pDT3	4.738,9	18.495,9	14.120,9	6.145,9	5.093,7	670,1	49,7	1,8	12,0	**49.328,9**
300pDT1	698,8	1.344,2	1.027,1	797,2	6.354,0	4.139,7	20.905,4	11.119,3	11.981,3	**58.367,2**
300pDT2	2.213,4	4.394,8	2.028,4	2.903,7	12.898,0	6.938,8	5.315,6	1.089,8	484,9	**38.267,4**
300pDT3	3.202,7	5.517,8	2.682,0	1.904,5	2.884,5	593,1	344,4	111,5	452,9	**17.693,4**
400pDT1	317,0	702,3	680,3	926,3	4.318,7	3.336,6	9.332,4	3.849,9	2.893,0	**26.356,7**
400pDT2	1.820,3	3.206,2	2.207,2	4.376,4	10.392,6	3.639,7	1.226,1	195,0	38,2	**27.101,8**
400pDT3	1.479,9	2.699,5	1.350,2	1.005,5	1.244,9	377,6	53,0	1,7	0,9	**8.213,3**
All	**52.104,5**	**110.046,7**	**66.628,1**	**52.731,3**	**163.333,9**	**84.042,1**	**110.066,9**	**46.084,9**	**41.566,4**	**726.604,7**

Table 27. Basic investment in DKK/m² floor area for performing the basic renovation of building elements important for energy in the various building types, construction periods and insulation standards.

Basic invest.	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK/m²	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	1.739	1.703	1.692	1.725	1.896	1.913	1.822	1.750	1.554	**1.730**
110DT2	1.920	1.836	1.793	1.834	2.037	2.069	1.976			**1.876**
110DT3	2.102	1.962	1.870	1.933	2.124					**2.001**
120DT1	1.731	1.674	1.668	1.814	2.087	2.116	1.973	1.935	1.566	**1.927**
120DT2	1.907	1.791	1.809	2.000	2.290	2.308	2.175			**2.069**
120DT3	2.119	1.896	1.901	2.102						**1.993**
130DT1	1.577	1.557	1.599	1.851	1.839	1.927	1.836	1.949	1.622	**1.823**
130DT2	1.750	1.698	1.790	2.055	2.193	2.226				**2.028**
130DT3	1.914	1.832	1.869	2.112	2.373					**1.978**
140pDT1	1.118			1.253	1.273	1.256	1.253	1.390	1.241	**1.268**
140pDT2	1.157	1.168	1.172	1.253	1.357	1.406	1.311			**1.280**
140pDT3	1.188	1.195	1.201	1.287	1.413	1.485				**1.230**
300pDT1	1.159	1.175	1.270	1.298	1.416	1.402	1.285	1.241	1.227	**1.280**
300pDT2	1.293	1.267	1.338	1.448	1.540	1.612	1.427	1.491		**1.464**
300pDT3	1.359	1.315	1.411	1.513	1.554					**1.399**
400pDT1	1.257	1.364	1.503	1.647	1.692	1.543	1.586	1.572	1.241	**1.536**
400pDT2	1.406	1.430	1.575	1.787	1.815	1.773	1.791			**1.695**
400pDT3	1.455	1.493	1.628	1.881	1.851					**1.606**
All	**1.626**	**1.531**	**1.533**	**1.704**	**1.880**	**1.908**	**1.622**	**1.590**	**1.379**	**1.665**

Table 28 shows the energy investment in DKK million in relation to the improvement of the building's energy efficiency. For example, for scenario 5, the energy investment corresponds to around DKK 1.2 million per year for the period up to 2050.

Table 28. Energy investment requirement in DKK million for the various scenarios in relation to the reduction of the heat requirement in relation to the basic renovation of building elements.

Scenario	1	2	3	4	5	6	7
Farmhouse	0	294	641	1,366	2,919	4,610	5,170
Detached house	0	1,337	4,320	8,692	19,880	31,886	37,725
Terraced house	0	106	782	1,334	3,879	6,300	7,645
Apartment building, etc.	0	647	2,243	3,159	5,685	8,139	9,252
Trade and services	0	210	1,420	2,199	5,198	8,755	10,313
Institutions	0	146	755	1,279	3,070	5,041	6,075
Total	0	2,739	10,162	18,028	40,631	64,731	76,179

Table 29 shows the relative increase in investment for the various energy scenarios.

Table 29. Relative percentage increase in investment requirement for the various scenarios in relation to the reduction of the heat requirement in relation to the basic renovation of building elements.

Scenario	1	2	3	4	5	6	7
Farmhouse	0.0	0.7	1.6	3.4	7.2	11.3	12.7
Detached house	0.0	0.4	1.3	2.7	6.1	9.8	11.6
Terraced house	0.0	0.2	1.1	1.9	5.5	9.0	10.9
Apartment building, etc.	0.0	0.6	1.9	2.7	4.9	7.0	8.0
Trade and services	0.0	0.2	1.2	1.9	4.5	7.7	9.0
Institutions	0.0	0.2	1.2	2.1	5.0	8.2	9.9
Total	0.0	0.4	1.4	2.5	5.6	8.9	10.5

Table 30 shows the energy investment requirement in relation to the annual heat saving for the various energy scenarios with scenario 1 as the reference both for the energy investment requirement and the annual heat saving.

Table 30. Energy investment requirement in DKK per kWh/year heat saving for the various scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	2.23	2.43	3.24	5.45	7.53	8.28
Detached house	-	2.24	2.47	3.27	5.82	8.03	9.20
Terraced house	-	2.21	2.50	3.13	6.69	9.07	10.53
Apartment building, etc.	-	2.24	2.48	2.81	4.27	5.63	6.29
Trade and services	-	2.17	2.50	2.71	5.03	7.32	8.33
Institutions	-	2.14	2.47	2.85	5.30	7.54	8.74
Total	-	2.23	2.47	3.06	5.44	7.54	8.60

Scenario 5

The results for scenario 5 are presented in greater detail in this section.

Table 31 shows the total investment requirement for the energy improvement of the building elements divided according to building types, construction periods and insulation standard.

Table 32 correspondingly shows the investment requirement in DKK/m² floor area for the energy improvement of building elements for the various building types, construction periods and insulation standards

Table 33 shows the energy investment requirement in relation to the annual heat saving with scenario 1 as the reference both for the energy investment requirement and the annual heat saving.

Table 31. Total investment requirement in DKK million for the energy improvement of the building elements divided according to building types, construction periods and insulation standard. Scenario 5

Energy invest.	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK million	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	182,3	204,0	46,0	10,7	23,2	35,9	95,1	29,3	26,5	**652,9**
110DT2	402,9	549,9	157,9	52,5	78,6	38,1	9,8	1,6	0,0	**1.291,3**
110DT3	362,2	444,9	114,0	39,8	12,9	0,5	0,9	0,0	0,0	**975,2**
120DT1	345,3	455,0	170,2	125,8	1518,4	1603,0	1814,8	386,4	248,4	**6.667,4**
120DT2	681,3	1702,3	1172,7	1029,9	3731,2	1233,4	166,5	3,9	3,6	**9.724,7**
120DT3	424,6	1332,5	869,6	544,0	300,0	12,7	3,5	0,4	1,0	**3.488,2**
130DT1	32,7	33,1	11,3	20,7	152,3	190,0	1414,7	291,2	121,0	**2.267,1**
130DT2	77,7	123,9	105,9	187,6	328,3	205,9	58,6	1,4	0,0	**1.089,3**
130DT3	76,0	149,7	106,7	89,2	79,9	14,5	5,2	0,4	0,6	**522,2**
140pDT1	16,1	43,8	34,0	41,6	137,8	79,0	451,6	159,3	140,3	**1.103,6**
140pDT2	98,4	273,3	168,3	172,1	558,7	176,7	101,8	7,3	2,3	**1.558,8**
140pDT3	250,9	1089,7	920,6	409,5	310,2	37,6	3,5	0,1	0,2	**3.022,3**
300pDT1	30,3	56,8	43,0	36,7	269,0	188,6	866,3	344,4	352,7	**2.187,8**
300pDT2	109,6	222,1	102,7	150,5	649,9	362,7	264,8	43,9	18,3	**1.924,3**
300pDT3	187,1	350,3	180,7	122,7	170,6	33,4	21,9	3,6	15,5	**1.085,8**
400pDT1	16,7	33,8	31,6	38,1	180,7	130,1	436,1	117,7	64,3	**1.049,1**
400pDT2	105,1	179,3	117,3	249,1	555,1	188,0	68,9	7,2	1,5	**1.471,6**
400pDT3	96,6	175,0	97,1	81,1	75,5	19,8	3,8	0,1	0,0	**549,0**
All	**3.495,8**	**7.419,4**	**4.449,5**	**3.401,5**	**9.132,1**	**4.550,0**	**5.787,9**	**1.398,1**	**996,2**	**40.630,5**

Table 32. Investment requirement in DKK/m² floor area for the energy improvement of building elements for the various building types, construction periods and insulation standards. Scenario 5

Energy invest.	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK/m²	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	95	93	92	89	102	105	108	65	36	**89**
110DT2	141	133	128	126	139	133	127			**135**
110DT3	204	191	178	187	206					**194**
120DT1	98	89	84	88	109	117	108	52	30	**92**
120DT2	139	124	117	131	146	145	140			**135**
120DT3	209	187	182	201						**192**
130DT1	84	80	79	84	86	97	114	71	36	**91**
130DT2	118	115	110	130	125	123				**122**
130DT3	158	159	156	167	162					**157**
140pDT1	42			50	44	42	59	37	29	**45**
140pDT2	52	55	53	59	57	58	68			**57**
140pDT3	63	70	78	86	86	83				**75**
300pDT1	50	50	53	60	60	64	53	38	36	**48**
300pDT2	64	64	68	75	78	84	71	60		**74**
300pDT3	79	83	95	98	92					**86**
400pDT1	66	66	70	68	71	60	74	48	28	**61**
400pDT2	81	80	84	102	97	92	101			**92**
400pDT3	95	97	117	152	112					**107**
All	**109**	**103**	**102**	**110**	**105**	**103**	**85**	**48**	**33**	**93**

Table 33. Energy investment requirement in DKK per kWh/year heat saving for the various building types, construction periods and insulation standards. Scenario 5 with scenario 1 as the reference.

Energy	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK/(kWh/year)	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	7.53	7.37	7.14	7.18	7.15	7.03	9.06	6.36	3.97	**7.26**
110DT2	5.93	5.58	5.51	5.53	5.89	6.02	7.87			**5.72**
110DT3	4.89	4.26	4.11	4.00	4.16					**4.44**
120DT1	7.58	6.82	6.24	6.35	6.98	7.37	8.98	5.41	3.57	**7.11**
120DT2	6.06	5.53	5.64	5.67	6.11	6.54	7.79			**5.96**
120DT3	4.94	4.06	3.96	4.03						**4.13**
130DT1	6.81	6.54	6.18	5.45	5.92	5.91	9.86	6.99	4.20	**7.89**
130DT2	5.94	5.70	5.82	6.31	5.48	5.72				**5.86**
130DT3	5.35	4.73	4.75	4.52	5.15					**4.91**
140pDT1	4.96			5.11	4.46	4.46	7.08	3.94	3.22	**4.91**
140pDT2	4.99	4.86	4.72	4.61	4.47	4.62	6.91			**4.74**
140pDT3	4.25	3.90	3.89	3.77	3.75	4.26				**3.89**
300pDT1	6.15	5.74	5.38	5.49	5.18	5.82	6.38	4.56	4.64	**5.45**
300pDT2	5.73	5.37	4.99	4.56	4.74	5.06	5.99	6.15		**5.10**
300pDT3	4.72	4.18	3.96	3.85	4.16					**4.26**
400pDT1	6.27	6.04	5.20	5.94	5.36	5.21	7.37	4.83	3.45	**5.78**
400pDT2	6.58	5.60	5.44	5.35	5.10	5.24	6.87			**5.40**
400pDT3	4.60	4.61	4.11	4.01	4.42					**4.39**
All	**5.57**	**4.80**	**4.61**	**4.79**	**5.54**	**6.21**	**8.02**	**5.20**	**4.00**	**5.44**

Annualised investment

The annualised investment in heat savings per kWh of heat saved is determined in the following section to facilitate comparisons with corresponding energy supply costs. The annualised investment is determined by dividing the investment by the present value factor and the annual heat saving.

The present value factor is determined in accordance with the Danish Energy Agency's guidance on 'Socio-economic calculation assumptions for energy prices and emissions' from May 2017. A discount rate of 4.0% per annum has been used in accordance with the 'Updated supplement on the discount rate, lifetime and reference to Guidelines on socio-economic analyses in the energy sector' issued by the Danish Energy Agency in June 2013.

The investments have been calculated over the lifetime of the renovated building element exclusive of taxes and VAT.

Table 34 shows the anticipated lifetimes for building components following renovation and the associated present value factor determined using a real interest rate of 4.0% per annum.

Table 34. Lifetime of building element following renovation and present value factor using a real interest rate of 4.0% per annum. Both calculated this year.

Building element	Lifetime	NPV factor
Façades		
External cavity walls	60	22.6
Solid exterior walls	60	22.6
Lightweight exterior walls	40	19.8
Basement exterior walls	60	22.6
Roof		
Loft	40	19.8
Flat roof	40	19.8
Windows		
Windows	30	17.3
Rooflights	30	17.3
External doors	30	17.3
Windows, general	30	17.3
Floors		
Slab	60	22.6
Crawl space	60	22.6
Basement floor	60	22.6
Heated slab	60	22.6
Heated crawl space	60	22.6

Table 35 shows the annualised investment in heat savings calculated in DKK/kWh. The investment has been calculated as a total for the scenarios with scenario 1 as a reference. Scenario 1 has been chosen as a reference because it corresponds to the basic renovation of building elements to fulfil the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould.

Table 36 correspondingly shows the calculated marginal annualised investment. Additional investments and additional savings have been used calculated from scenario to scenario in the calculation of the marginal annualised investment in DKK/kWh. For example, the marginal investment for scenario 5 has thus been calculated based on the extra investment in heat savings in scenario 5 in relation to scenario 4 and the associated heat savings.

It can be seen that the marginal annualised investments in heat savings calculated in DKK/kWh for the most recent scenarios is somewhat higher than the total annualised investments for the same scenarios.

Table 35. Annualised investment in heat savings calculated in DKK/kWh. Total investment for scenarios.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	0.10	0.13	0.17	0.27	0.38	0.41
Detached house	-	0.10	0.13	0.17	0.29	0.40	0.46
Terraced house	-	0.10	0.14	0.17	0.34	0.46	0.53
Apartment building, etc.	-	0.10	0.13	0.15	0.22	0.29	0.32
Trade and services	-	0.10	0.14	0.15	0.26	0.37	0.42
Institutions	-	0.09	0.14	0.15	0.27	0.38	0.44
Total	-	0.10	0.13	0.16	0.28	0.38	0.43

Table 36. Annualised investment in heat savings calculated in DKK/kWh. Marginal investment for the scenario.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	0.10	0.15	0.23	0.67	1.10	2.27
Detached house	-	0.10	0.15	0.24	0.73	1.08	2.24
Terraced house	-	0.10	0.15	0.25	0.82	1.05	2.19
Apartment building, etc.	-	0.10	0.15	0.21	0.60	1.07	2.17
Trade and services	-	0.10	0.15	0.16	0.66	1.09	1.87
Institutions	-	0.09	0.15	0.19	0.67	1.09	1.99
Total	-	0.10	0.15	0.22	0.70	1.08	2.15

Scenario 5

The results for scenario 5 are presented in greater detail in this section.

Table 37 shows the total annualised investment in heat savings calculated in DKK/kWh for the various building types, construction periods and insulation standards with scenario 1 as the reference.

Table 38 correspondingly shows the total marginal annualised investment in heat savings calculated in DKK/kWh for the various building types, construction periods and insulation standards.

Table 37. Annualised investment in heat savings calculated in DKK/kWh for the various building types, construction periods and insulation standards. Total investment for scenario 5.

Energy	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK/kWh	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	0.39	0.38	0.37	0.37	0.37	0.36	0.47	0.33	0.22	**0.37**
110DT2	0.30	0.28	0.28	0.28	0.30	0.31	0.40			**0.29**
110DT3	0.24	0.21	0.20	0.19	0.20					**0.22**
120DT1	0.39	0.35	0.32	0.33	0.36	0.38	0.46	0.29	0.20	**0.37**
120DT2	0.30	0.28	0.28	0.29	0.31	0.33	0.40			**0.30**
120DT3	0.24	0.20	0.19	0.20						**0.20**
130DT1	0.35	0.34	0.32	0.28	0.31	0.31	0.51	0.37	0.23	**0.41**
130DT2	0.30	0.29	0.29	0.32	0.28	0.29				**0.30**
130DT3	0.26	0.23	0.23	0.22	0.26					**0.24**
140pDT1	0.26			0.27	0.24	0.24	0.37	0.22	0.18	**0.26**
140pDT2	0.26	0.25	0.25	0.24	0.23	0.24	0.36			**0.25**
140pDT3	0.22	0.20	0.19	0.19	0.19	0.21				**0.19**
300pDT1	0.32	0.30	0.28	0.28	0.27	0.30	0.33	0.24	0.25	**0.28**
300pDT2	0.29	0.27	0.25	0.23	0.24	0.25	0.30	0.32		**0.26**
300pDT3	0.23	0.21	0.19	0.19	0.21					**0.21**
400pDT1	0.32	0.31	0.26	0.30	0.28	0.27	0.38	0.26	0.19	**0.30**
400pDT2	0.33	0.28	0.27	0.27	0.26	0.27	0.35			**0.27**
400pDT3	0.23	0.23	0.20	0.19	0.22					**0.22**
All	**0.28**	**0.24**	**0.23**	**0.24**	**0.28**	**0.32**	**0.41**	**0.28**	**0.22**	**0.28**

Table 38. Annualised investment in heat savings calculated in DKK/kWh for the various building types, construction periods and insulation standards. Marginal investment for scenario 5.

Energy	p1	p2	p3	p4	p5	p6	p7	p8	p9	pS
DKK/kWh	-1890	1890-1929	1930-1949	1950-1959	1960-1972	1973-1978	1979-1998	1999-2006	2007-2016	Total
110DT1	0.91	0.91	0.92	0.93	0.89	0.83	1.07	1.17	1.03	**0.94**
110DT2	0.65	0.68	0.72	0.67	0.72	0.70	0.85			**0.68**
110DT3	0.46	0.54	0.61	0.61	0.59					**0.51**
120DT1	0.89	0.87	0.84	0.83	0.85	0.88	1.10	1.17	1.13	**0.95**
120DT2	0.63	0.63	0.60	0.62	0.71	0.76	0.89			**0.67**
120DT3	0.44	0.51	0.52	0.53						**0.51**
130DT1	0.88	0.81	0.79	0.78	0.73	0.72	1.11	1.19	1.08	**1.04**
130DT2	0.55	0.57	0.55	0.66	0.60	0.64				**0.62**
130DT3	0.46	0.47	0.52	0.58	0.66					**0.53**
140pDT1	0.90			0.82	0.76	0.64	1.09	1.08	0.99	**0.94**
140pDT2	0.66	0.64	0.62	0.71	0.59	0.56	0.85			**0.63**
140pDT3	0.47	0.48	0.49	0.61	0.48	0.42				**0.49**
300pDT1	0.90	0.71	0.81	0.58	0.67	0.66	0.85	0.79	0.86	**0.78**
300pDT2	0.72	0.64	0.62	0.59	0.61	0.62	0.75	0.77		**0.64**
300pDT3	0.50	0.49	0.45	0.48	0.49					**0.50**
400pDT1	0.68	0.69	0.65	0.78	0.66	0.68	0.93	0.99	0.80	**0.81**
400pDT2	0.69	0.62	0.64	0.64	0.61	0.61	0.78			**0.63**
400pDT3	0.55	0.56	0.54	0.50	0.55					**0.55**
All	**0.60**	**0.59**	**0.57**	**0.61**	**0.69**	**0.74**	**1.01**	**1.03**	**0.95**	**0.70**

Private economic calculation assumptions

The assumptions specified in the following section have been used for the calculation of private economy. All prices are 2017 prices. Energy prices for the private economy calculations include charges corresponding to the energy price that private consumers, businesses and public institutions, etc. pay for energy for space heating. Prices have been calculated excluding VAT.

Current energy prices and loan terms have been used as a basis.

Energy prices

Table 39 shows the energy prices used in DKK/kWh excluding VAT. The prices are based on the Danish Energy Agency's statistics for the first quarter of 2017. The price of electricity for space heating has been used, which costs less than other electricity consumption in housing, etc. An average COP of 3.00 has been assumed for heat pumps.

Table 39. Private economic energy prices in 2017 excluding VAT and including energy price increases in % p.a.

Fuel	Energy price, 2017 DKK/kWh	Price increase % p.a.
Natural gas	0.52	1.6
District heating	0.40	1.1
Electricity (electric heating)	1.20	1.1
Electricity (heat pump)	0.40	1.1

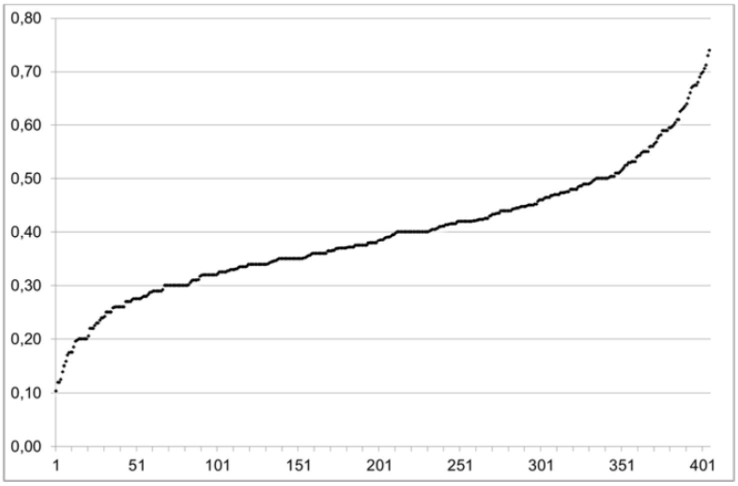


Figure 3. District heating price in DKK/kWh, excluding VAT, for Danish district heating plants. Direct variable consumption-dependent percentage.

There are large differences in the price of district heating for the various supply undertakings. Figure 3 shows the direct variable consumption-dependent district heating price in DKK/kWh, excluding VAT for over 400 supply undertakings in the Danish Energy Agency’s statistics.

The average direct variable supply-dependent district heating price is DKK 0.37/kWh, excluding VAT. This only includes direct variable charges on bills. Direct variable expenses amount to approximately two thirds of the total charges for district heating. The remainder constitutes various forms of subscriptions and contributions. However, a number of district heating companies use a billing system where parts of the contribution or subscription depend on the power requirement or the heat consumption for the previous year. Thus, part of what is normally considered as a fixed charge for district heating is actually a variable charge that is dependent on the power requirement or the consumption for the previous year.

The charges amount to around half of the total price, excluding VAT for natural gas. The charges amount to around DKK 0.10/kWh for district heating and around DKK 0.4/kWh for electricity used for heating, excluding PSO charges. In determining the price increases for the private economic prices, it is assumed that the charges will be maintained and only the energy price itself will increase. The price increase for energy is calculated excluding inflation and in 2017 prices.

The price increase in % p.a. is determined based on data in 'Socio-economic calculation assumptions for energy prices and emissions', Danish Energy Agency, May 2017. This data is in turn based on projected energy supplies up until 2030 in the 'Danish Energy Agency's Baseline Projection 2017' from March 2017. Therefore, the price increases used do not take account of the energy transformation required after 2030 up to the final target in 2050 for fossil-free energy supplies, including the development of the requisite capacity to cover peak loads, reinforcement of the transmission system and developing solutions for peak load levelling. These challenges will probably mean that in determining the price of energy for consumers in future, there will be a greater focus on power peaks, which in turn is closely related to the design heat output. However, it is not possible to incorporate this into the calculations because of a lack of knowledge of future developments. It has therefore been necessary to base the calculations only on the anticipated increase in kWh prices.

Because net energy price increases are positive for the relevant forms of supply, the economics in investing in heat savings will become more favourable over the years. However, because the renovation of buildings is normally driven by circumstances other than a desire for heat savings, there is little sense in speculatively systematically postponing renovations.

Borrowing rates and calculations periods

A real interest rate of 1.0% p.a. has been used in determining the private economy. This has been determined taking into account the actual interest rates and inflation in recent years and the potential to deduct interest expenses. The economy for housing has been calculated over 30 years, while for other buildings it has been calculated over 20 years in accordance with typical loan maturity periods for the building types in question.

The borrowing rates, calculation period and residual value have otherwise been determined as defined in Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 on the calculation of cost-optimal levels and the supplementary guidelines. The residual value has been calculated in accordance with the EU Regulation by linear depreciation and the application of a real interest rate of 1.0% p.a. Using this interest rate, the discount factor for 20 years is 0.820 and the discount factor for 30 years is 0.742. For housing, a renovated building element with a remaining lifetime of 40 years after renovation will following the 30-year calculation period be included with a discounted residual value of: 0.742 • (40 years - 30 years) / 40 years = 0.19 of the initial investment.

Heat supply

The heat supply potential is also of significance for the private economy.

The current heat supply for the existing building stock in accordance with BBR is shown below. Heat supply in this case must be understood in very general terms, i.e. whether this is district heating, natural gas, oil, individual heat pumps or other sources, e.g. stoves or direct electric heating.

Knowledge or expectations regarding future heat supplies are required to assess the private economy in relation to heat savings in buildings.

The potential future heat supply in existing buildings will to some extent be dependent on the existing heat supply, the potential for conversion and the general conditions around the buildings, i.e. whether it is open land or a built-up area.

Table 40 shows the existing heat supply for the buildings calculated as a percentage of buildings with district heating, natural gas, oil, heat pumps or other sources. The same information is calculated in Table 41 in relation to floor area for buildings with different heat supplies.

Farmhouses are currently primarily heated using oil or other sources, e.g. firewood, wood pellets and wood chips. However, around 10% of farmhouses already have heat pumps.

Around 44% of detached houses are supplied by district heating, 39% have natural gas or oil, and 13% have other sources of heating. Only 4% of detached houses have heat pumps.

Around 66% of terraced houses are supplied by district heating and 22% have natural gas. The remaining 12% have other sources of heating, including 4% with oil and 1% with heating pumps.

Table 40. Percentage of number of buildings with various types of heat supply.

	Farmhouse	Detached house	Terraced housing	Apartment building, etc.	Trade and services	Institutions
District heating	1.8	44.0	65.7	77.2	35.8	46.4
Natural gas	2.6	24.0	21.4	9.3	12.6	15.3
Oil	45.8	14.9	3.7	6.5	12.8	10.2
Heat pump	10.0	3.6	0.9	0.7	1.1	1.1
Other	39.8	13.5	8.2	6.4	37.7	27.0

Table 41. Percentage of floor area with various types of heat supply.

	Farmhouse	Detached house	Terraced housing	Apartment building, etc.	Trade and services	Institutions
District heating	1.9	43.4	67.1	88.1	55.6	70.9
Natural gas	2.7	24.2	20.7	6.7	18.6	15.6
Oil	44.1	14.8	3.9	3.2	8.8	6.3
Heat pump	10.8	4.2	1.1	0.3	0.5	0.6
Other	40.6	13.4	7.2	1.8	16.4	6.6

77% of apartment buildings and 88% of the floor area of apartment housing are heated using district heating. In cases where there is a significant difference between the two percentages, this is because the category also covers semi-detached houses and other small residential buildings with horizontal apartment boundaries that are smaller than traditional apartment buildings.

These are typically located in areas with ordinary detached houses and therefore have the same heat supply as these. Larger apartment buildings are thus largely connected to a district heating supply. In contrast, heat pumps are very rare.

For trade and services and institutions, 36% and 46% of buildings respectively are heated by district heating, with this representing 56% and 71% respectively of the floor area. Larger properties are also connected to district heating in this case. The remainder of the buildings are heated using natural gas, oil or other sources, including around 1% heated using heat pumps.

It must be anticipated in the long-term that heating supplies will primarily consist of district heating and individual heat pumps, with district heating dominating in urban areas and individual heat pumps dominating in rural areas. In the suburbs and smaller towns, there will probably be either district heating or individual heat pumps, depending on what is already there today and how supplies develop.

Private economy

Private economy is calculated in this section in connection with investments in heat savings in the existing building stock. In this case, private economy also covers economy for commercial premises and public institutions. Economy is calculated using the assumptions in the previous section.

Economy is calculated as:
- The present value of the investment,
- The return on the investment,
- The marginal return on the investment.

Present value

The total present value of the investment in heat savings when renovating a building is calculated by:
- Discounting the future heat savings back to the time of investment using the present value method.
- Adding the residual value at the end of the calculation period discounted back to the time of the investment,
- Deducting the investment itself from the improvement of the building element.

A positive present value indicates that the investment gives a profit overall, including in relation to any loans or interest.

The total present value of the investment in heat savings is calculated using scenario 1 as the reference because scenario 1 corresponds to the basic renovation of building elements to fulfil the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould.

Table 42 shows the total present value for buildings heated using natural gas. The present value is positive for all scenarios and building types. However, the present value falls slightly between scenario 5 and scenario 6 and subsequently falls further between scenario 6 and scenario 7. This is an indication that the overall profit is decreasing. See the subsequent section on marginal economy regarding the optimisation of profits. For example, for detached houses and scenario 5, this corresponds to a present value of DKK 261/m^2 floor area.

Table 42. Total present value of investment in heat savings in DKK million. Natural gas Current prices.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	2,069	3,992	6,110	6,851	6,815	6,573
Detached house	-	9,397	26,229	38,180	42,349	42,234	39,732
Terraced house	-	755	4,628	6,110	6,709	6,742	6,179
Apartment building, etc.	-	4,550	13,489	16,503	18,099	18,076	17,613
Trade and services	-	978	5,320	7,559	8,335	8,073	7,621
Institutions	-	688	2,882	4,154	4,593	4,446	4,127
Total	-	18,437	56,541	78,617	86,935	86,386	81,845

Table 43 shows the total present value for buildings heated using district heating or individual heat pumps. Heating using district heating and individual heat pumps is shown together because these initially have the same price for heating.

The present value for all scenarios and building types is also positive in this case. The present value of the investment is generally slightly lower than for buildings heated using natural gas because of the lower price for heating. It can also be seen in this case that the difference is greater between scenario 5 and scenario 6.

Table 43. Total present value of investment in heat savings in DKK million. District heating or individual heat pump. Current prices.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	1,417	2,683	4,018	4,196	3,779	3,475
Detached house	-	6,436	17,535	25,000	25,412	22,549	19,395
Terraced house	-	517	3,075	3,998	3,834	3,296	2,579
Apartment building, etc.	-	3,116	9,008	10,934	11,501	10,907	10,316
Trade and services	-	687	3,616	5,125	5,235	4,485	3,906
Institutions	-	484	1,965	2,808	2,856	2,439	2,041
Total	-	12,657	37,882	51,883	53,034	47,456	41,713

Table 44 shows the total present value for buildings heated using district heating or individual heat pumps if it is assumed in the long-term that the renovation work will be performed more efficiently and thus the investment requirement is reduced by 10%. This is shown to increase the present value slightly for all scenarios and building types. For example, for scenario 5, the present value is increased by a total of DKK 3 141 million.

Table 44. Total present value of investment in heat savings in DKK million. District heating or individual heat pump. 10% improved cost efficiency.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	1,435	2,736	4,130	4,428	4,147	3,889
Detached house	-	6,520	17,918	25,739	27,033	25,131	22,453
Terraced house	-	524	3,149	4,117	4,157	3,813	3,206
Apartment building, etc.	-	3,157	9,208	11,209	11,972	11,578	11,077
Trade and services	-	697	3,714	5,268	5,547	5,004	4,516
Institutions	-	491	2,015	2,890	3,038	2,736	2,399
Total	-	12,823	38,741	53,353	56,175	52,408	47,540

Table 45 shows the total present value for buildings heated using individual heat pumps if the electricity cost is reduced by DKK 0.15/kWh to DKK 0.25/kWh, and the heat is therefore DKK 0.05/kWh cheaper compared with the heat pump's anticipated COP of 3.00. This is shown to displace the maximum point of the present value to between scenarios 4 and 5. The values for apartment buildings, trade and services and institutions have been included for the sake of completeness, as it must be anticipated that the majority of these will be heated using district heating.

Table 45. Total present value of investment in heat savings in DKK million. Individual heat pump. Reduced electricity costs.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	1,217	2,281	3,375	3,380	2,846	2,523
Detached house	-	5,526	14,866	20,952	20,211	16,503	13,149
Terraced house	-	444	2,597	3,349	2,951	2,238	1,474
Apartment building, etc.	-	2,676	7,631	9,224	9,475	8,705	8,075
Trade and services	-	590	3,042	4,305	4,191	3,277	2,655
Institutions	-	415	1,655	2,355	2,271	1,763	1,339
Total	-	10,868	32,073	43,560	42,479	35,333	29,215

Total return on investment

The total private economic return on the investment in heat savings is calculated in the following section. The return factor is an indication of how good the investment is. Scenario 1 has again been used as a reference because it corresponds to the basic renovation of building elements to fulfil the minimum requirements for building technology and indoor climate, taking into account the risk of moisture damage and mould. A return factor of 1.00 means that the investment is only just repaid over the calculation period of 30 years for housing and 20 years for other buildings taking into account the value of the heat savings, interest expenses and a smaller residual value discounted at the time of investment corresponding to what has been included in the present value. If the factor is greater than 1.00, a profit will be made on the investment. If the factor is less than 1.00, this means that the investment will only partially be repaid.

Table 46 shows the total return on the investment for buildings heated using natural gas. The assumptions correspond to those used in Table 42 for the calculation of the total present value. The total return on the investment is greatest for the first scenarios, but falls in later scenarios. However, it is typically greater than 1.00 for all scenarios and building types.

Table 46. Return on investment in heat savings. Natural gas Current prices. Overall economy.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	8.05	7.23	5.47	3.35	2.48	2.27
Detached house	-	8.03	7.07	5.39	3.13	2.32	2.05
Terraced house	-	8.12	6.92	5.58	2.73	2.07	1.81
Apartment building, etc.	-	8.03	7.01	6.22	4.18	3.22	2.90
Trade and services	-	5.67	4.75	4.44	2.60	1.92	1.74
Institutions	-	5.72	4.82	4.25	2.50	1.88	1.68
Total	-	7.73	6.56	5.36	3.14	2.33	2.07

Table 47 shows the total return on the investment for buildings heated using district heating or individual heat pumps. It can be seen that the return factor for the investment in the heat savings is slightly lower for buildings heated using district heating or individual heat pumps than for buildings heated using natural gas. However, it is clearly greater than 1.00 for all scenarios and building types, with a minimum value of 1.34 for terraced houses and institutions in scenario 7.

Table 47. Return on investment in heat savings. District heating or individual heat pump. Current prices. Overall economy.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	5.83	5.18	3.94	2.44	1.82	1.67
Detached house	-	5.81	5.06	3.88	2.28	1.71	1.51
Terraced house	-	5.88	4.93	4.00	1.99	1.52	1.34
Apartment building, etc.	-	5.81	5.02	4.46	3.02	2.34	2.12
Trade and services	-	4.28	3.55	3.33	2.01	1.51	1.38
Institutions	-	4.32	3.60	3.20	1.93	1.48	1.34
Total	-	5.62	4.73	3.88	2.31	1.73	1.55

Table 48 shows the total return on the investment for buildings heated using district heating or individual heat pumps if the renovation work will be performed more efficiently and thus the investment requirement is reduced by 10%. This is shown to increase the return factor slightly for all scenarios and building types so that the minimum value is increased to 1.44 for institutions in scenario 7.

Table 48. Return on investment in heat savings. District heating or individual heat pump. 10% improved cost efficiency. Overall economy.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	6.43	5.74	4.36	2.69	2.00	1.84
Detached house	-	6.42	5.61	4.29	2.51	1.88	1.66
Terraced house	-	6.49	5.47	4.43	2.19	1.67	1.47
Apartment building, etc.	-	6.42	5.56	4.94	3.34	2.58	2.33
Trade and services	-	4.69	3.91	3.66	2.19	1.64	1.49
Institutions	-	4.74	3.97	3.51	2.10	1.60	1.44
Total	-	6.20	5.24	4.29	2.54	1.90	1.69

Table 49 shows the total return on investment in heat savings for buildings heated using individual heat pumps if the electricity cost is reduced by DKK 0.15/kWh to DKK 0.25/kWh and the heat is therefore DKK 0.05/kWh cheaper compared with the heat pump's anticipated COP of 3.00. The assumptions correspond to those used in Table 45 for the calculation of the total present value. It can be seen that the total return on the investment is still greater than 1.00 for all scenarios and building types, but that the minimum value has fallen to 1.19 for terraced houses in scenario 7. The values for apartment buildings, trade and services and institutions have largely been included for the sake of completeness, as it is anticipated that the majority of these will be heated using district heating.

Table 49. Return on investment in heat savings. Individual heat pump. Reduced electricity costs. Overall economy.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	5.15	4.56	3.47	2.16	1.62	1.49
Detached house	-	5.13	4.44	3.41	2.02	1.52	1.35
Terraced house	-	5.19	4.32	3.51	1.76	1.36	1.19
Apartment building, etc.	-	5.13	4.40	3.92	2.67	2.07	1.87
Trade and services	-	3.81	3.14	2.96	1.81	1.37	1.26
Institutions	-	3.85	3.19	2.84	1.74	1.35	1.22
Total	-	4.97	4.16	3.42	2.05	1.55	1.38

Marginal return on investment

In this section, the marginal private economic return on investment is calculated in connection with investments in heat savings in the existing building stock. The return factor is used for the investment in the calculation but is calculated from scenario to scenario in this case. For example, the marginal economy for scenario 5 has therefore been calculated based on the extra investment in heat savings in scenario 5 in relation to scenario 4 and the associated heat savings and the economy associated with this. The assumptions otherwise correspond to those used in the previous section for calculating the total return on the investment in heat savings.

Table 50 shows the marginal return on the investment for buildings heated using natural gas. The marginal return on the investment is greatest for the first scenarios but falls in later scenarios such that it is around 1.0 for scenario 6, and somewhat dependent on building type.

Table 50. Return on investment in heat savings. Natural gas Current prices. Marginal economy for the scenario.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	8.05	6.53	3.92	1.48	0.98	0.57
Detached house	-	8.03	6.64	3.73	1.37	0.99	0.57
Terraced house	-	8.12	6.73	3.69	1.24	1.01	0.58
Apartment building, etc.	-	8.03	6.60	4.29	1.63	0.99	0.58
Trade and services	-	5.67	4.59	3.88	1.26	0.93	0.71
Institutions	-	5.72	4.60	3.43	1.24	0.93	0.69
Total	-	7.73	6.13	3.81	1.37	0.98	0.60

Table 51 shows the marginal return on the investment for buildings heated using district heating or individual heat pumps. It can be seen that the return factor for the investment in the heat savings is slightly lower for buildings heated using district heating or individual heat pumps than for buildings heated using natural gas. For buildings heated using district heating or individual heat pumps, the return factor is around 1.05 for scenario 5 and somewhat dependent on building type, while the return factor is around 0.77 for scenario 6.

Table 51. Return on investment in heat savings. District heating or individual heat pump. Current prices. Marginal economy for the scenario.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	5.83	4.64	2.84	1.11	0.75	0.46
Detached house	-	5.81	4.72	2.71	1.04	0.76	0.46
Terraced house	-	5.88	4.78	2.68	0.94	0.78	0.47
Apartment building, etc.	-	5.81	4.69	3.10	1.22	0.76	0.47
Trade and services	-	4.28	3.42	2.94	1.04	0.79	0.63
Institutions	-	4.32	3.43	2.61	1.03	0.79	0.62
Total	-	5.62	4.40	2.78	1.05	0.77	0.50

Table 52 shows the marginal return on the investment for buildings heated using district heating or individual heat pumps if the renovation work will be performed more efficiently and thus the investment requirement is reduced by 10%. It can be seen that the marginal return factor thereby is around 1.14 for scenario 5 and around 0.83 for scenario 6.

Table 52. Return on investment in heat savings. District heating or individual heat pump. 10% improved cost efficiency. Marginal economy for the scenario.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	6.43	5.16	3.14	1.21	0.82	0.49
Detached house	-	6.42	5.24	2.99	1.13	0.82	0.49
Terraced house	-	6.49	5.31	2.95	1.02	0.84	0.50
Apartment building, etc.	-	6.42	5.21	3.43	1.34	0.82	0.50
Trade and services	-	4.69	3.77	3.22	1.10	0.83	0.65
Institutions	-	4.74	3.78	2.85	1.09	0.83	0.64
Total	-	6.20	4.88	3.06	1.14	0.83	0.53

Table 53 shows the total return on investment in heat savings for buildings heated using individual heat pumps if the electricity cost is reduced by DKK 0.15/kWh to DKK 0.25/kWh and the heat is therefore DKK 0.05/kWh cheaper compared with the heat pump's anticipated COP of 3.00. The marginal return factor therefore falls to around 0.95 for scenario 5. The values for apartment buildings, trade and services and institutions have largely been included for the sake of completeness, as it is anticipated that the majority of these will be heated using district heating.

Table 53. Return on investment in heat savings. Individual heat pump. Reduced electricity costs. Marginal economy for the scenario.

Scenario	1	2	3	4	5	6	7
Farmhouse	-	5.15	4.06	2.51	1.00	0.68	0.42
Detached house	-	5.13	4.13	2.39	0.93	0.69	0.43
Terraced house	-	5.19	4.18	2.36	0.84	0.71	0.43
Apartment building, etc.	-	5.13	4.11	2.74	1.10	0.69	0.43
Trade and services	-	3.81	3.03	2.62	0.96	0.74	0.60
Institutions	-	3.85	3.04	2.33	0.95	0.74	0.59
Total	-	4.97	3.86	2.46	0.95	0.70	0.47

References

Potentielle varmebesparelse ved løbende bygningsrenovering frem til 2050 (Potential heat savings during ongoing renovations of buildings until 2050), SBi 2013:08. Wittchen, Kim B.; Kragh, Jesper & Aggerholm, Søren. Danish Building Research Institute, University of Aalborg. Copenhagen, 2014.

Bygnings- og boligregisteret (Central Register of Buildings and Dwellings), BBR. www.bbr.dk. (2017)

Energimærkning af bygninger (Energy labelling of buildings). www.ens.dk. (2017)

Energistatistik 2015 (Energy Statistics 2015). Danish Energy Agency, 2016.

Bygningsreglement 2015 (Danish Building Regulations 2015), BR 15. Danish Construction, Transport and Housing Authority, 1 July 2017. www.bygningsreglementet.dk. (2017)

Enhedspriser til beregning af omkostninger ved varmebesparelser (Unit prices for calculating costs in connection with heat savings). NIRAS. Notat til Energistyrelsen (Memorandum to the Danish Energy Agency), 29 March 2017.

Vejledning i samfundsøkonomiske analyser på energiområdet (Guidelines on socio-economic analyses in the energy sector). Danish Energy Agency, April 2005.

Opdateret tillægsblad om kalkulationsrente, levetid og reference til Vejledning i samfundsøkonomiske analyser på energiområdet (Updated supplement on the discount rate, lifetime and reference to Guidelines on socio-economic analyses in the energy sector). Danish Energy Agency, June 2013.

Samfundsøkonomiske beregningsforudsætninger for energipriser og emissioner (Socio-economic calculation assumptions for energy prices and emissions). Danish Energy Agency, May 2017.

Basisfremskrivning 2017 (Baseline projection 2017). Danish Energy Agency, March 2017.

COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

NOTICES FROM EUROPEAN UNION INSTITUTIONS, BODIES, OFFICES AND AGENCIES EUROPEAN COMMISSION. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (2012/C 115/01).

This report was commissioned by the Danish Energy Agency, which was seeking to estimate the potential heat savings amongst the existing building stock and associated investments and the profitability of these investments for building owners.

Awareness of the potential for heat savings is an important consideration in light of the Danish Government's goal of fossil-free energy supplies by 2050. Heating buildings accounts for around a third of total Danish energy consumption, and therefore saving heat is a key factor in reducing the capacity that will be required for the renewable energy supply system of the future.

The report's calculations show *inter alia* that it will be necessary to reduce heat consumption by a third if the entire Danish building stock is also to attain energy efficiencies corresponding to the requirements of the current building regulations (BR15 and BR18) in connection with necessary renovations. The total investment in energy efficiency will be around DKK 40 billion and the investment would be very profitable for building owners because their investment would be returned somewhere between two and three times over during a 30-year period, varying according to the heat source used by the individual building owner for space heating.

The report does not present any conclusions regarding the optimal level of heat savings from a socio-economic perspective. To answer this question, it would also be necessary to perform economic analyses of the future energy supply system.

The report is accompanied by a spreadsheet in Microsoft Excel format containing the results of the heat saving calculations and investment requirements for the seven different scenarios included in the report.

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