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COST-OPTIMAL LEVELS OF MINIMUM ENERGY PERFORMANCE REQUIREMENTS IN THE DANISH BUILDING REGULATIONS

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Cost-optimal levels of minimum energy performance requirements in the Danish Building Regulations

Søren Aggerholm

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Preface

The purpose of this report is to evaluate the energy requirements in the Danish Building Regulation in relation to the COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012 on a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. The Delegated Regulation is required in the EPBD (recast): DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast).

The evaluation is performed by the Danish Building Research Institute on request from the Danish Energy Agency.

Danish Building Research Institute, Aalborg University Copenhagen
Department of Energy and Environment
September 2013

Søren Aggerholm
Head of the department

Introduction

The Delegated Regulation requires Member States to set minimum energy performance requirements for buildings and building elements with a view to achieving cost-optimal levels. It is up to the Member States to decide whether the national benchmark used as the final outcome of the cost- optimal calculations is the one calculated for a macroeconomic perspective (looking at the costs and benefits of energy efficiency investments for the society as a whole) or a strictly financial viewpoint (looking only at the investment itself). National minimum energy performance requirements should not be more than 15 % lower than the outcome of the cost-optimal results of the calculation taken as the national benchmark.

The understanding of the Delegated Regulation is supported by a guideline: 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). The guidelines are not legally binding, they provide relevant additional information to the Member States and reflect accepted principles for the cost calculations required in the context of the Regulation. As such, the guidelines are intended for facilitating the application of the Regulation. It is the text of the Regulation which is legally binding and which is directly applicable in the Member States.

The Danish regulation in question is the Danish Building Regulations 2010, BR10 introduced in December 2010. It also includes the 4 amendments publish where the last is in force from 1. January 2013. BR10 can also be read at www.bygningsreglementet.dk in an updated version inclusive of the amendments. BR10 is basically in Danish but there is an English translation of the first version of BR10 from December 2010 and the three first amendments.

Denmark has long tradition and experience in evaluating the cost-efficiency of the energy requirements in the Danish Building Regulations and in analysing the saving potential in relation to tightening the requirements and other initiatives to improve the energy efficiency of the building stock in practice both in relation to new buildings, in relation to existing buildings and in relation to encourage the implementation of energy saving measures in buildings and in the habits of building owners and occupants.

The latest evaluations and analysis are published in:

- Tighten requirements to new buildings 2010 and in future (SBi 2009:04)
- Energy requirements to new buildings 2020 - Economical Analyses SBi (2011:18)
- Potential energy savings in the existing buildings (SBi 2009:05)
- The energy demand of Danish buildings in 2050 (SBi 2010:56)
- Means to promote energy savings in buildings (SBi 2009:06)

The effort has focus on the Danish needs and the publications above are all in Danish. Part of the content has also been published in English in relation to different European projects and in different international summary report and articles e.g.:

- Danish building typologies - Participation in the TABULA project. (SBi 2012:01)
- Building typologies in the Nordic countries - Identification of potential energy saving measures. (SBi 2012:04)
- Introducing cost-optimal levels for energy requirements (REHVA Journal, 3/2012)
- Energy saving potentials - A case study on the Danish building stock. (ECEEE 2011 Summer Study)

At the moment there is an intensive effort to develop an improved strategy for the energy saving in existing buildings. The effort is headed by the Danish Minister of Climate, Energy and Buildings Martin Lidegaard and operated by the Danish Energy Agency with support from the Danish Building Research Institute and in close collaboration with the whole building branch. The process was started in August 2012 with the establishment of 5 network groups from different parts of the branch asked to develop idea's for the improvement of energy savings in the existing building stock. In relation to the start of the work the informative publication: "Task Force. Network for energy renovation - Collection and presentation of existing core knowledge on energy renovation of existing buildings" (SBi 2012:09) was developed and handed out.

In relation to the midterm seminar of the network primo February 2013 a number of analysis is published (In Danish). The analysis includes:

- Compliance with the requirements in the Building Regulations
- Future prof component requirements
- Renovation and heat pumps - Smart grid and low temperature district heating
- Model for behaviour effect on energy consumption
- Incentives and means to promote energy savings in buildings
- Relation between energy label and selling price
- Heat savings by continues renovation of building up till 2050

The network will deliver its idea's to the minister in May and the ministry then have to develop and present the new strategy for energy savings in existing building before the end of 2013.

Main results and conclusions

The purpose of the report is to analyse the cost optimality of the energy requirements in the Danish Building Regulations 2010, BR10 to new building and to existing buildings undergoing major renovation.

The energy requirements in the Danish Building Regulations have by tradition always been based on the cost and benefits related to the private economical or financial perspective. Macro economical calculations have in the past only been made in addition. The cost optimum used in this report is thus based on the financial perspective. Due to the high energy taxes in Denmark there is a significant difference between the consumer price and the macro economical for energy. Energy taxes are also paid by commercial consumers when the energy is used for building operation e.g. heating, lighting, ventilation etc.

In this chapter the main results of the analysis of the cost optimality of the energy requirements in the Danish Building Regulations 2010 to new building and to existing buildings undergoing major renovation are summarised inclusive of also the component requirements and the sensitivity analysis. The conclusion of the analysis is at the end of the chapter.

Main results

Energy requirements to new buildings

Table 1 summarises the cost optimality of the energy requirements to new buildings in the Danish Building Regulations 2010, BR10. The gap is in % of the cost optimum level of requirements in kWh/m^2 ann. primary energy inclusive of renewables. Negative gap indicates the requirements in the Danish BR 10 being tighter than the cost optimum. BR 10 is the present minimum requirements in the Danish BR 10. LEB2015 is Low Energy Building 2015 - the already in BR 10 defined requirements for 2015. B2020 is Building 2020 - the already in BR 10 defined requirements for 2020. Only the relevant heat supply sources in relation to the Danish heat plan act is included.

The relatively high energy consumption in the BR10 office building mainly relates to the electricity used for lighting.

Table 1. Cost optimality of the energy requirements to new buildings in the Danish Building Regulations 2010. For the different building types and heat supply the table shows the cost optimum in kWh/m^2 ann. primary energy and the gap between the cost optimum level and the Danish requirements in %.

Building type	Heat supply	Cost optimal	Deviation to cost optimal, %		
		kWh/m^2 ann.	BR 10	LEB2015	B2020
Single family house	District heating	68,7	- 15,7	- 44,9	- 57,0
	Heat pump	51,1	- 2,8	- 49,8	- 58,0
Multifamily house	District heating	53,6	- 9,2	- 36,1	- 44,7
Office building	District heating	51,7	31,2	- 16,0	- 37,3
Weighted average	DK mix		2,8	- 34,4	- 48,8

Requirements to existing buildings undergoing major renovation

Table 2 summarises the cost optimality of the energy requirements in the Danish Building Regulations 2010 to existing buildings undergoing major renovation. The figures are for a building undergoing a complete renovation inclusive of all building elements except the foundations. Often also e.g. slap on ground will be untouched even in relation to a major renovation. 2015 and 2020 is the requirement to existing building with the already know tightening of requirements to windows in 2015 and in 2020.

Table 2. Cost optimality of the energy requirements in the Danish Building Regulations 2010 to existing buildings undergoing major renovation. For the different building types, year of construction and heat supply the table shows the cost optimum in kWh/m^2 ann. primary energy and the gap between the cost optimum level and the Danish requirements in %.

Building type	Heat supply	Cost optimal	Deviation to cost optimal, %		
		kWh/m^2 ann.	BR 10	2015	2020
Single family house, 1930	District heating	153,6	0,3	- 1,9	- 3,3
	Natural gas	181,6	0,4	- 2,0	- 3,4
	Heat pump	226,3	1,8	- 0,6	- 2,0
Single family house, 1960	District heating	128,6	- 4,9	- 9,1	- 11,7
	Natural gas	134,2	3,4	- 1,6	- 4,8
	Heat pump	120,6	- 1,5	- 6,7	- 9,8
Multifamily house, 1930	District heating	70,3	3,4	- 0,1	- 2,3
Multifamily house, 1960	District heating	75,3	3,8	- 1,5	- 4,6
Office building, 1960	District heating	90,2	3,7	- 2,1	- 5,7
Office building, 1980	District heating	130,8	- 6,6	- 10,8	- 13,0
Weighted average	DK mix		0,1	- 4,0	- 6,4

Primary energy demand

Table 3 summarises the primary energy demand (inclusive of renewables) in kWh/m^2 ann. for the different building types and heat supply fulfilling the energy requirements to new buildings in the Danish Building Regulations 2010. The primary energy factor for the energy supply's is as today (2012).

In table 4 the same is shown for the primary energy demand exclusive of renewables. With the future increase in renewable in both the district heating and the electricity production the primary energy demand exclusive of renewables for the buildings will reduce equivalent.

Table 3. Primary energy demand (inclusive of renewables) in kWh/m^2 ann. for the different building types and heat supply fulfilling the energy requirements to new buildings in the Danish Building Regulations 2010.

Building type	Heat supply	Primary energy in kWh/m^2 ann.		
		BR 10	LEB2015	B2020
Single family house	District heating	57,9	37,9	29,5
	Heat pump	49,7	25,7	21,5
Multifamily house	District heating	48,4	34,3	29,7
Office building	District heating	67,9	43,5	32,5

Table 4. Primary energy demand exclusive of renewables in kWh/m² ann. for the different building types and heat supply fulfilling the energy requirements to new buildings in the Danish Building Regulations 2010.

Building type	Heat supply	Primary energy excl. ren. in kWh/m² ann.		
		BR 10	LEB2015	B2020
Single family house	District heating	36,6	23,1	17,9
	Heat pump	36,2	18,7	15,7
Multifamily house	District heating	30,0	20,8	18,0
Office building	District heating	46,7	28,5	21,1

Table 5 summarises in the same way the primary energy demand inclusive of renewables in kWh/m^2 ann. for the different building types, year of construction and heat supply fulfilling the energy requirements in the Danish Building Regulations 2010 to existing buildings undergoing major renovation. Starting point indicated is for a typical nearly untouched building only having been improved in the past with double pane windows and a little loft or roof insulation. In table 6 the same is summarised for primary energy exclusive of renewables.

Table 5. Primary energy demand (inclusive of renewables) in kWh/m² ann. for the different building types, year of construction and heat supply fulfilling the energy requirements in the Danish Building Regulations 2010 to existing buildings undergoing major renovation.

Building type	Heat supply	Starting point	Primary energy in kWh/m² ann.		
		kWh/m² ann.	BR 10	2015	2020
Single family house, 1930	District heating	315,9	154,1	150,7	148,6
	Natural gas	440,7	182,2	177,9	175,4
	Heat pump	456,6	230,4	225,0	221,8
Single family house, 1960	District heating	193,4	122,4	116,9	113,6
	Natural gas	256,8	138,7	132,0	127,8
	Heat pump	273,2	118,8	112,5	108,7
Multifamily house, 1930	District heating	176,3	72,7	70,2	68,7
Multifamily house, 1960	District heating	123,5	78,1	74,1	71,8
Office building, 1960	District heating	231,9	93,5	88,4	85,1
Office building, 1980	District heating	181,3	121,5	116,1	113,2

Table 6. Primary energy demand exclusive of renewables in kWh/m² ann. for the different building types, year of construction and heat supply fulfilling the energy requirements in the Danish Building Regulations 2010 to existing buildings undergoing major renovation.

Building type	Heat supply	Starting point	Primary energy excl. ren. in kWh/m² ann.		
		kWh/m² ann.	BR 10	2015	2020
Single family house, 1930	District heating	193,0	93,7	91,6	90,3
	Natural gas	436,1	180,8	176,5	174,0
	Heat pump	338,6	167,2	163,3	160,9
Single family house, 1960	District heating	118,8	74,6	71,0	69,0
	Natural gas	252,7	137,4	130,7	126,7
	Heat pump	198,4	86,2	81,5	78,8
Multifamily house, 1930	District heating	95,3	44,2	42,8	41,9
Multifamily house, 1960	District heating	77,3	49,7	47,2	45,9
Office building, 1960	District heating	152,3	62,2	59,3	57,3
Office building, 1980	District heating	121,0	82,7	79,6	77,8

Component requirements to the envelope in new buildings

The component requirements to the building envelope elements in new buildings show gaps to cost optimality in the range of 2 - 48 %. This gives the designer a wide flexibility to select the design of the building. The energy efficiency of the building as such is anyhow controlled by the energy frame requirement.

The heat loss itself is also controlled by the requirement to the total heat loss from the building envelope exclusive of windows and doors. In the three new reference buildings the difference to cost optimality for the individual building elements in the envelope are in the range from a gap of 16 % to an excessive tightness of 45 % for the buildings complying with the 2010 requirement. For the buildings complying with the Low Energy Building 2015 requirement the excessive tightness is 0 - 45 %. For the new buildings complying with the Building 2020 requirement the excessive tightness is 0 - 62 %.

Component requirements to existing buildings undergoing renovation

In relation to component requirements to building envelope elements undergoing renovation the excessive tightness is 0 - 40 %, with a few exception where there is a gap of 19 % and 28 %. The two gap relates to loft insulation in houses heated by natural gas and to insulation on concrete basement slaps. The two situations are both related to the basic U-value requirement not being tight enough, not to the influence of the rentability provision.

Sensitivity analysis

The sensitivity analysis shows that higher energy price development or higher financial interest rate development has very small influence on the location of the cost optimal point. There is a very small tendency for the cost optimum to be moved to a higher energy efficiency level (lower primary energy consumption) if there is an additional energy price increase. The opposite is the case if the rates increase, without being followed by the energy price. The change is less than the resolution in energy efficiency for building due to the steps in energy efficiency coming from the steps in energy solutions e.g. related to available insulation thickness.

PV

PV are in general not cost efficient today, but are very close to the balance point of being cost efficient in new buildings with major electricity consumption included in the energy for building operation. In the case of just a small increase in cost for electricity PV will be beneficial.

Conclusions

New buildings

In relation to the new housing examples the present minimum energy requirements in BR 10 all shows gaps that are negative with a deviation of up till 16 % from the point of cost optimality. With the planned tightening of the requirements to new houses in 2015 and in 2020, the energy requirements can be expected to be tighter than the cost optimal point, if the costs for the needed improvements don't decrease correspondingly.

In relation to the new office building there is a gap of 31 % to the point of cost optimality in relation to the 2010 requirement. In relation to the 2015 and 2020 requirements there are negative gaps to the point of cost optimality based on today's prices.

If the gaps for all the new buildings are weighted to an average based on mix of building types and heat supply for new buildings in Denmark there is a gap of 3 % in average for the new building. The excessive tightness with today's prices is 34 % in relation to the 2015 requirement and 49 % in relation to the 2020 requirement.

Component requirements

The component requirement to building elements in the envelope of new building opens for very wide flexibility to the design of the building. It might be relevant to consider if some of the component requirements should be tightened to ensure the reasonable insulation of all elements in the envelope of new buildings. The requirement to the heat loss from the building envelope exclusive of windows and door are in better balance with cost optimality.

PV

PV is not cost beneficial today, but is very close to be cost beneficial especially in building with high electricity consumption included in the building operation e.g. office buildings and houses heated by heat pumps. If the energy price development increases - or the cost for installation of PV reduces - it will soon be cost beneficial to install PV in new buildings. When it happens the point of cost optimal will move significantly towards lower primary energy consumption in the buildings.

Existing buildings

The component requirement to elements in the building envelope and to installations in existing buildings adds up to significant energy efficiency improvement of existing building both in the case of major renovation and in the case of several less comprehensive renovations.

Component requirements

The component requirements are in nearly all cases tighter than the point of cost optimal. It could be considered to tighten the requirement to insulation in open loft spaces where it is more beneficial to add a significant higher thickness of insulation compared to insulation in other roof constructions e.g. parallel roof. It could also be a possibility in relation to the insulation of the basement slap, but it has to be combined with an analysis of the moister conditions in the unheated basement.

Major renovation

In relation to major renovation the gap between requirements and cost optimality is very small. The reason is probably that the Danish energy requirements to existing building in itself includes a rentability factor provision that brings the requirements very close to cost optimality. The tightening of the requirements to windows in 2015 and 2020 seems to move the requirements to existing buildings beyond cost optimality. Probably this will be solved by the change in price for efficient windows.

Danish building stock

The information on the Danish building stock is based on data in the Danish Building and Housing Register, BBR. The national register was established in 1976 based on data from local registers. Selected aggregated data from BBR is available in English from Danish Statistics in the Statistical Yearbook and on www.statistikbanken.dk.

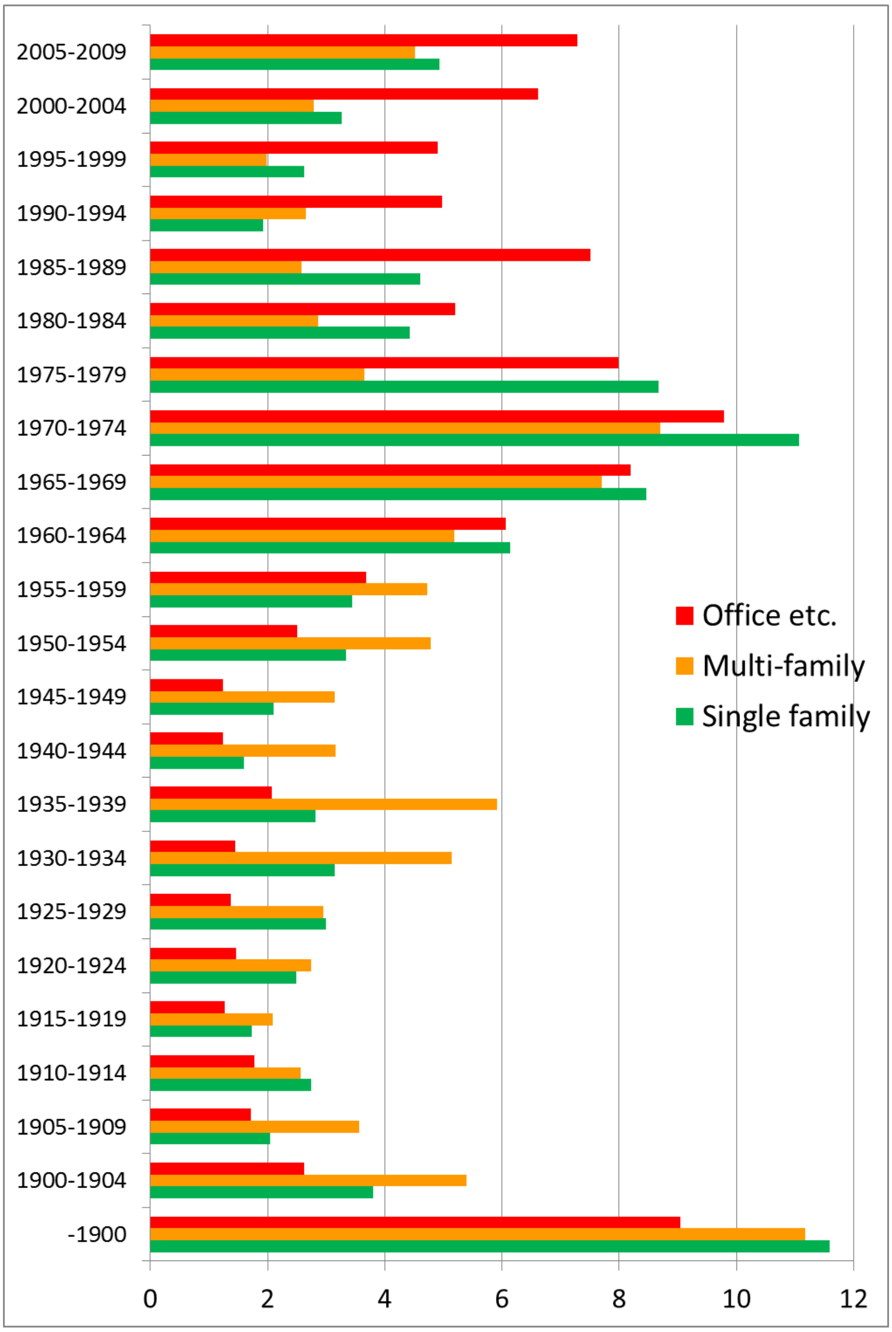
Gross floor area of different building types in the Danish building stock. Last year included are buildings constructed in 2009.

Building type	Gross floor area in 1.000 m^2: - 2009	2005-9
Farm houses	25.655	492
Detached single family houses	166.094	7.587
Row houses	36.403	3.184
Apartment blocks	84.542	3.550
Student residence	1.483	146
Residential home	4.332	393
Other housing	840	35
Administrative and commercial buildings etc.	62.846	5.996
Hotel, restaurant etc.	6.304	271
Transport and commerce etc.	1.378	166
Museum, church, library etc.	4.848	160
Education and research etc.	20.784	645
Hospitals etc..	4.074	167
Day-care institutions	3.372	157
Other institutions	1.347	79
Total	424.302	23.028

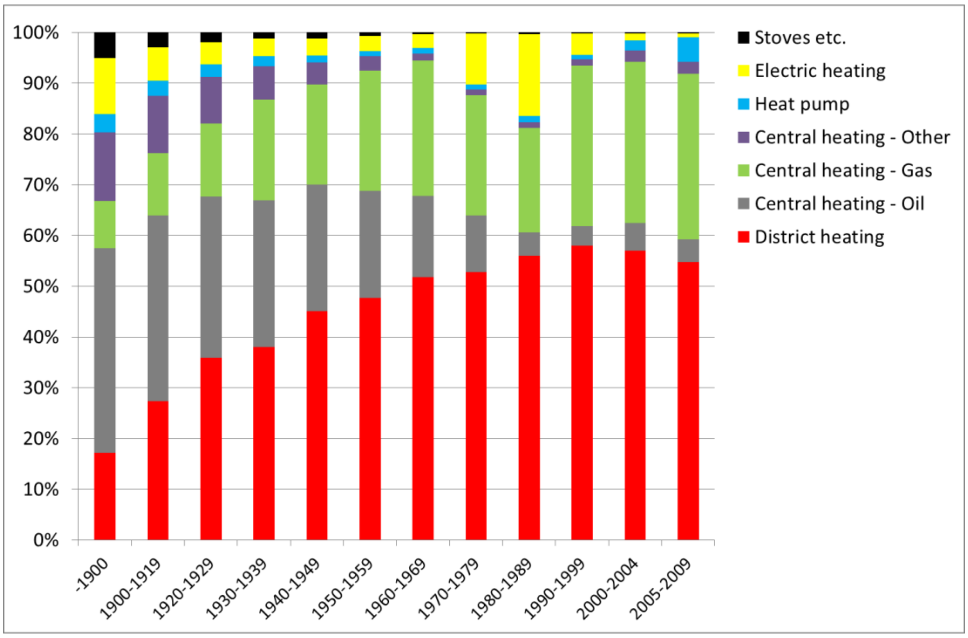
In the statistics for the Danish building stock in this section of the report the term Single family houses includes Farm houses, Detached single family houses and Row houses. Multifamily houses includes Apartment blocks, Student residence, Residential home and Other housing. The term Office buildings includes all other types of non-dwelling listed in the table. Summer houses, workshops and industrial buildings are not included in this statistics of the building stock.

Overview of the Danish building stock

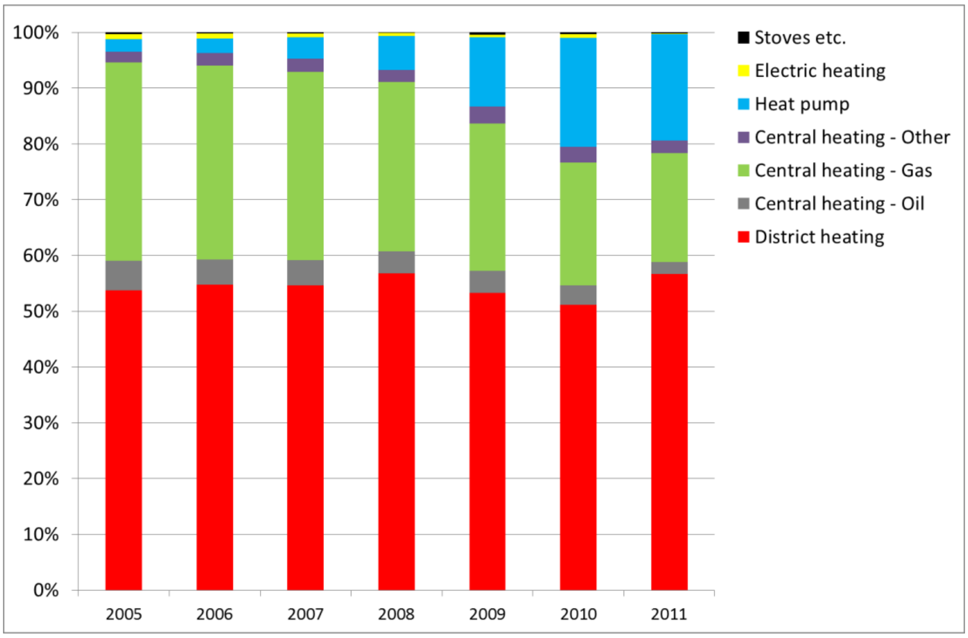
Building type	No. buildings	No. dwellings	Gross floor area, 1000 m^2
Single family houses	1.443.632	1.514.201	228.152
Multifamily houses	89.717	1.016.017	91.197
Office buildings etc.	94.458	-	104.953
Total	1.627.807	2.530.218	424.302



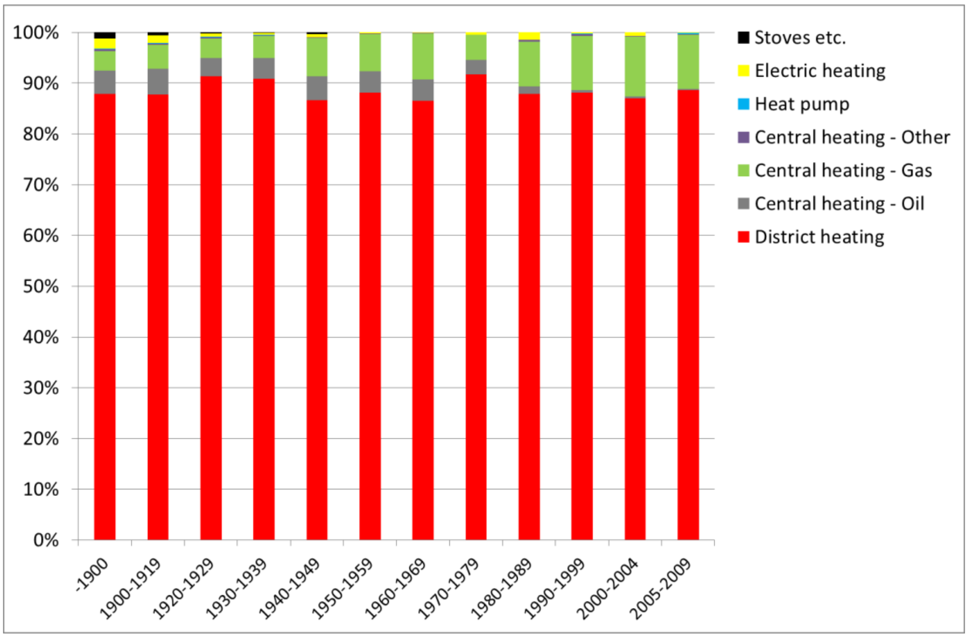
Construction year for the Danish building stock for each of the three lump building types: Single family house, Multifamily house and Office. The percentage is per each of the three lump building types.



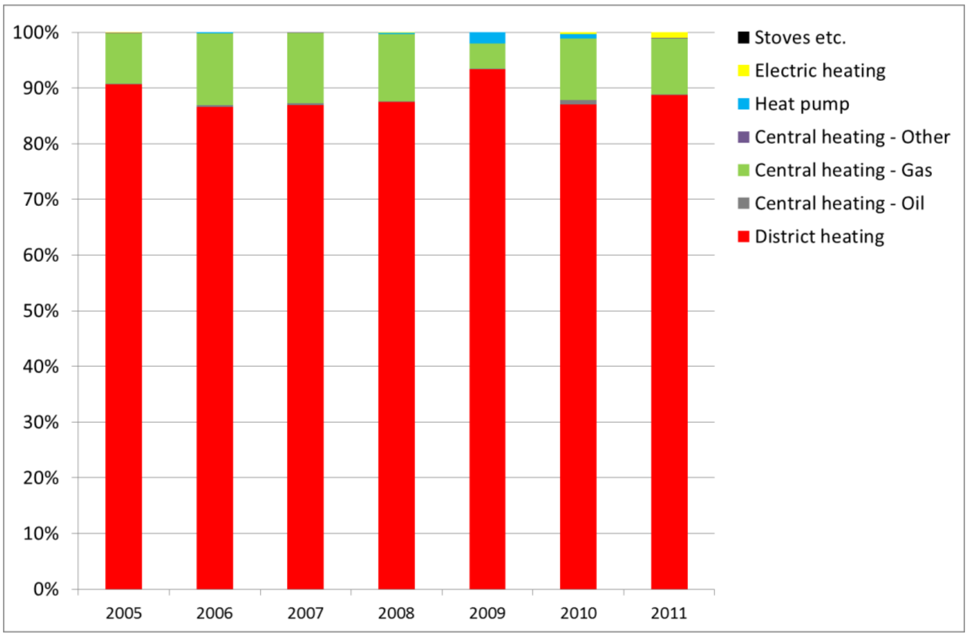
Heating supply in existing single family houses.



Heating supply in recently constructed single family houses.



Heating supply in existing multifamily houses.

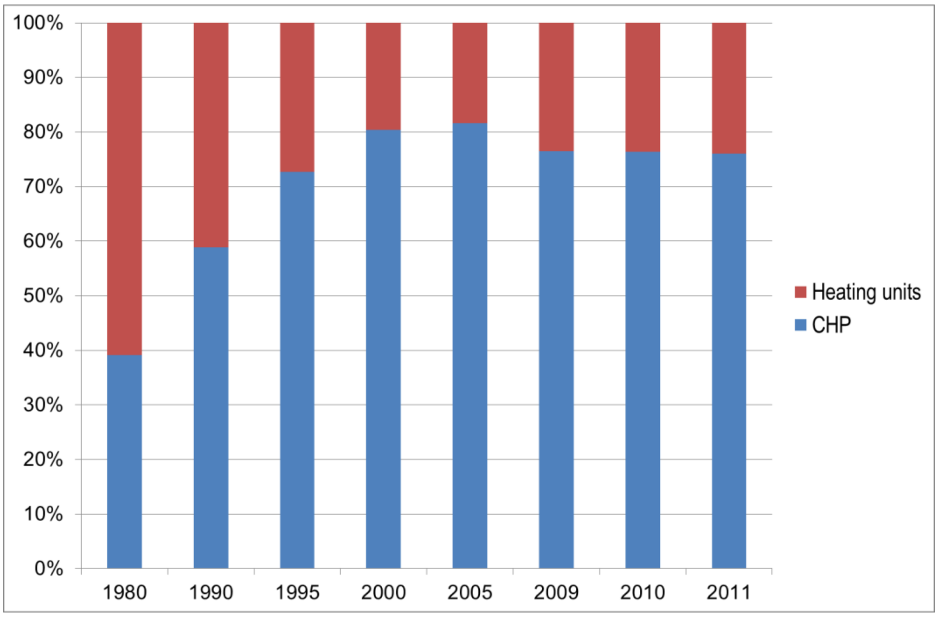


Heating supply in recently constructed multifamily houses.

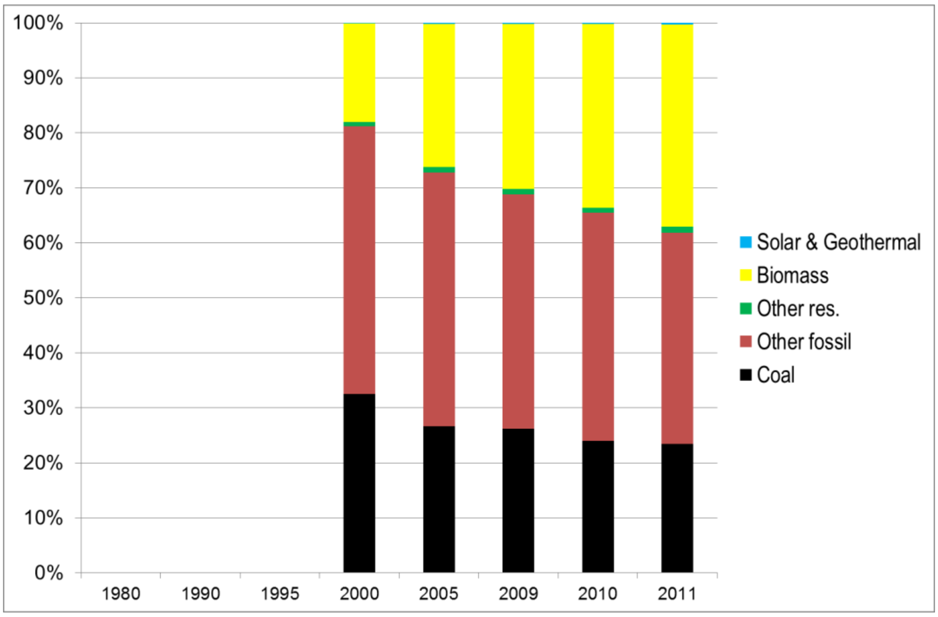
Danish energy supply

The general Danish energy policy is briefly described in: "Energy Policy in Denmark" published by the Danish Energy Agency in December 2012.

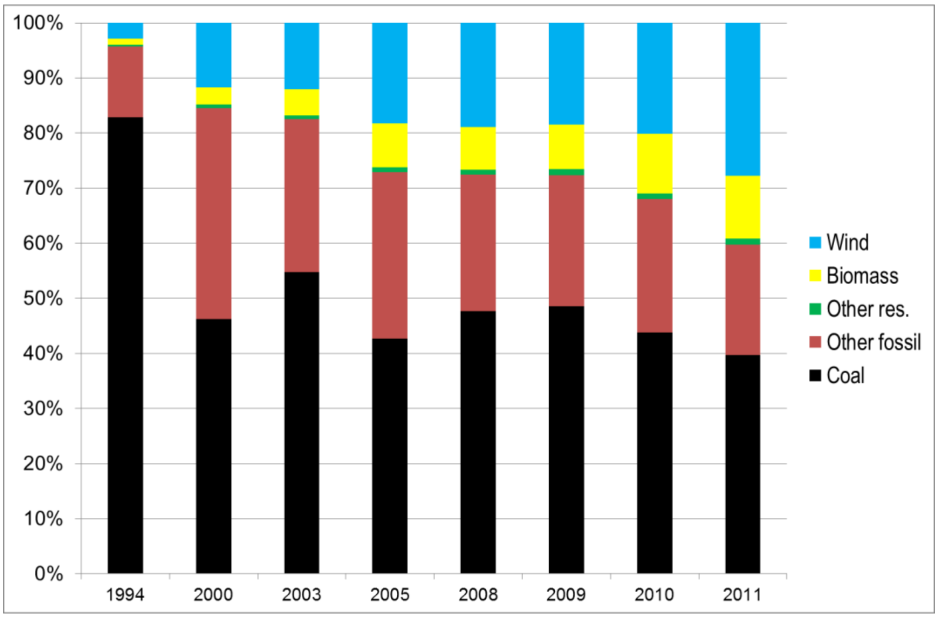
The information on the present Danish energy supply system in this chapter is based on data from the Danish Energy Statistics 2011.



Share of CHP in the Danish district heating production



Fuels in the Danish district heating production.



Fuels in the Danish electricity production.

Fuel types in the Danish energy supply system and use of fossil fuel for extraction. Extraction is in percentage of extracted energy.

Fuel	Extraction in %
Renewable:	
Wind	0
Solar	0
Geothermal	0
Hydro	0
Biogas	10
Biomass:	10
- Straw	
- Wood	
- Bio oil	
- Waste - renewable	
Heatpump	10
Fossil fuels	
Waste - non renewable	10
Oil	10
Natural gas	10
Coal	20

Extraction is not included in the Danish energy statistics except for natural gas produced in the Danish area of the North Sea.

The figures from the Danish energy statistic used to calculate the primary energy factors and the CO_2-emission rates are adjusted to include the fossil fuel used for extraction of the fuel.

A heating efficiency of 200 % is used to calculate the energy need for heating in relation to CHP production in district heating and power supply systems. The 200 % efficiency is close to the figures calculated for the systems using more detailed exergy calculations.

Total primary energy factor, fossil energy factor and CO_2-emission rate in kg-CO_2/MWh for the energy supply to Danish building. National average values for Denmark. Inclusive of energy used to extract the fuels.

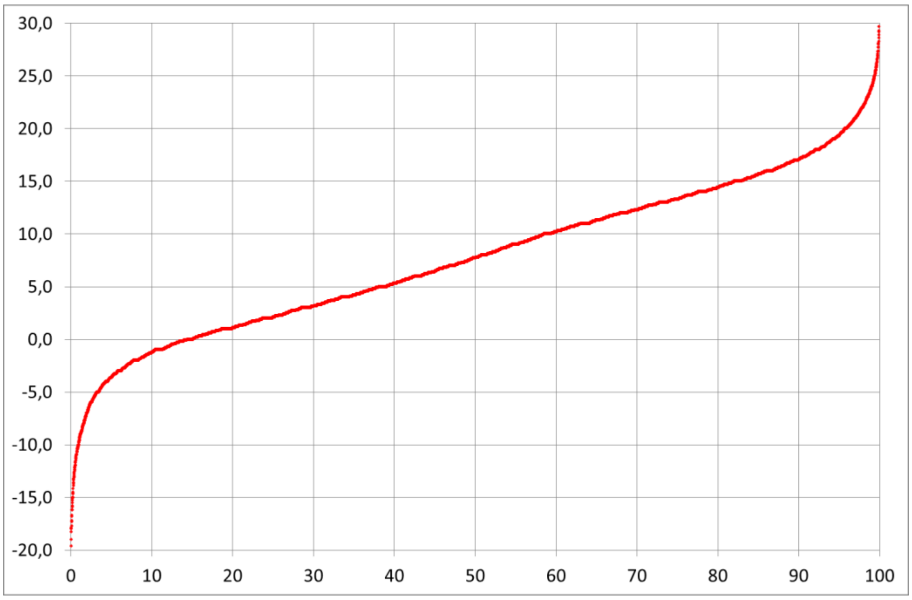
Fuel	Total primary energy factor	Fuel factor	Fossil energy factor	CO_2-emission kg-CO2/MWh
Natural gas	1,10	1,10	1,10	225
District heating	0,89	0,89	0,54	141
Electricity	2,48	2,17	1,80	531

Danish weather

All Denmark is one climate zone. The information on the Danish weather is from the Danish Design Reference Year, DRY.

Weather data in the Danish design reference year, DRY.

Month	Average external temperature C	Avg. min. ext. temperature C	Avg. max. ext. temperature C	Global solar radiation kWh/m²	Sun shine hours
January	- 0,5	- 4,1	2,5	16	41
February	- 1,0	- 4,7	1,8	32	65
March	1,7	- 2,6	5,5	65	127
April	5,6	1,8	9,0	114	181
May	11,3	5,4	16,2	163	256
June	15,0	10,4	19,3	165	257
July	16,4	11,9	20,7	160	247
August	16,2	12,1	20,4	134	221
September	12,5	8,9	16,3	82	166
October	9,1	5,2	12,5	43	98
November	4,8	2,8	6,7	19	42
December	1,5	- 1,0	3,1	10	28
Year	7,8			1.002	1.729



Sta External temperature in the Danish design reference year, DRY.

tistics for the Danish weather from the last 10 years indicate a 1,0 - 1,5 C higher external temperature in the heating period compared to DRY. The temperatures in summer and the solar radiation in both winter and summer are in average about the same as in DRY.

The traditional Danish heating degree-days are measured to an internal base temperature of 17 C. The counting of degree-days starts when the external average daily temperature in 3 days continuously are below 12 C and stops when the external average daily temperature in 3 days continuously are above 10 C. Based on the years 1941-1980 the heating period are 233 days from September 24 to May 14. Based on that method there are is 2906 degree-days per annum.

The typical room temperature in the building stock are in average anticipated to be 20 C. To calculate the average heat loss through the building envelope 3 x 233 degree-days has to be added ending with approx. 3.600 degree-days per annum.

Danish Building Regulations

The present Danish building regulation are Building Regulation 2010, BR10. It was introduced in December 2010. Since then there are four amendments to the regulations. The last of the amendments was introduced January 2013, se reference list.

The relevant sections of the Danish Building Regulation 2010 including the energy requirements to new building and to existing buildings undergoing renovation in relation to the Delegated Regulations are:

Energy requirements to new building:

7. Energy consumption
7.2 Energy performance frameworks in new buildings
7.3 Change of use and extensions

Energy requirements to existing building undergoing renovation:

7. Energy consumption
7.3 Change of use and extensions
7.4 Conversion and other alterations to the building and replacement of boilers etc.

Energy requirements to installations relevant to both new buildings and to existing buildings undergoing renovation:

6. Indoor climate
6.3.1 Ventilation
6.5 Light conditions

7. Energy consumption
7.1 General
7.6 Minimum thermal insulation

8. Services
8.1 General
8.2 Distribution systems for heating, cooling and domestic hot water
8.3 Ventilation systems
8.5 Combustion plants and exhaust systems
8.6 Solar heating systems, solar photovoltaic arrays, cooling systems and heat pumps.

Appendix 6 in BR10 contains:

1. A summary of measures that are often cost-effective to implement in relation to existing buildings undergoing renovation.
2. Assumptions used in the calculations associated with calculating the energy demands of new buildings

The core energy requirements in BR10 to new building and to existing buildings undergoing renovation are summarised on the following pages.

There are also energy requirement in BR10 to holiday homes and temporary portable cabins. These types of building are not included in the Delegated Regulations and will not be addressed in this report. The same goes for the energy requirements to lifts, the requirement to perform energy labelling of new and existing buildings and the requirement to install meters on building level, per flat and for individual meters for hot water production, heating of air and fan power in ventilation plants, heat pumps, lifts, comfort cooling systems, cooling of servers and server rooms.

The regulation in relation to availability and requirements in relation to heating supply to buildings are in the Danish Heat Planning act, see last section of this chapter.

Energy requirements to new buildings

In the case of dwellings, student accommodation, hotels etc., the total demand of the building for energy supply for heating, ventilation, cooling and domestic hot water per m² of heated floor area must not exceed (52.5 + 1650/A) kWh/m²/year, where A is the heated floor area. By "Heated floor area" means the total floor area of the storeys or parts thereof which are heated. [BR10: 7.2.2 (1)]

For offices, schools, institutions etc., the total demand of the building for energy supply for heating, ventilation, cooling and domestic hot water and lighting per m² of heated floor area must not exceed (71.3 + 1650/A) kWh/m²/year, where A is the heated floor area. [BR10: 7.2.3 (1)]

In the case of buildings or building sections whose requirements include, for example, a high level of lighting, extra ventilation and high consumption of domestic hot water, or which are used for extended periods, or buildings with high ceilings, the energy performance framework must be increased by the resulting calculated energy consumption. Process energy such as ventilation of fume cabinets is not included in the energy performance framework. [BR10: 7.2.3 (3)]

Buildings heated to more than 5°C and up to 15°C must fulfil the same energy performance framework as office building. Regardless of temperature level, the energy performance framework must be determined using an indoor temperature of 15°C.

Calculations must take account of solar heat gain, body heat and the heat accumulating properties of the building. Verification must be on the basis of a simplified calculation method, using monthly average weather data etc.; see Appendix 6. Verification must be on the basis of SBi Guidelines 213, "Bygningers energibehov" [Energy demands of buildings]. This provision also applies to buildings with balanced mechanical ventilation and cooling.

Buildings must be built such that the design transmission loss does not exceed 5 W per m² of the building envelope in the case of single-storey buildings, 6 W for two-storey buildings and 7 W for buildings with three storeys or more. The calculation does not factor in the area of windows and doors nor transmission loss through them. [BR10: 7.2.1 (8)]

Insulation of individual building elements in the building envelope must be at least on a par with the values stated in table 7.6. [BR10: 7.2.1 (7)]

The calculation of transmission areas, transmission loss and heat loss framework must use the DS 418, Code of Practice, Calculation of heat loss from buildings. The insulation properties of materials must be determined in accordance with relevant DS/EN standards. [BR10: 7.1 (6)]

Air changes through leakage in the building envelope must not exceed 1.5 l/s/m² of the heated floor area when tested at a pressure of 50 Pa. The result of the pressure test must be expressed as the average of measurements using overpressure and under-pressure. Testing of air changes must be determined on the basis of DS/EN 13829, Thermal performance of buildings – Determination of air permeability of buildings –Fan pressurisation method. [BR10: 7.2.1 (4)]

Table 7.6 Minimum thermal insulation in new buildings

Table of U values	**U value W/m² K**
External walls and basement walls in contact with the soil.	0.30
Suspended upper floors and partitions to rooms/spaces that are unheated or heated to a temperature more than 8 K lower than the temperature in the room/space concerned.	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.20
Suspended floors below floors with floor heating adjoining heated rooms/spaces.	0.50
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.20
External doors, rooflights, doors and hatches to the outside or to rooms/spaces that are unheated and these as well as glass walls and windows to rooms that are heated to a temperature more than 5 K below the temperature in the room concerned.	1.80
Table of linear losses	**Linear loss W/mK**
Foundations around rooms/spaces that are heated to a minimum of 5°C.	0.40
Foundations around floors with floor heating.	0.20
Joint between external wall and windows or external doors and hatches	0.06
Joint between roof structure and rooflights or skylight domes.	0.20

Low energy buildings class 2015

Dwellings, student accommodation, hotels etc. may be classified as a class 2015 low energy building when the total demand for energy supply for heating, ventilation, cooling and domestic hot water per m² of heated floor area does not (30 + 1000/A) kWh/m²/year. [BR10: 7.2.4.1]

Offices, schools, institutions and other buildings not covered by 7.2.4.1 may be classified as class 2015 low energy buildings when the requirement for supplied energy for heating, ventilation, cooling, domestic hot water and lighting does not exceed (41 + 1000/A)kWh/m²/year. [BR10: 7.2.4.2]

Low energy buildings class 2015 must be built such that the design transmission loss does not exceed 4.0 W per m² of the building envelope in the case of single-storey buildings, 5.0 W per m² for two-storey buildings and 6.0 W for buildings with three storeys or more. [BR10: 7.2.1 (10)]

In the case of low energy buildings class 2015 air changes through the building envelope must not exceed 1.0 l/s pr. m². [BR10: 7.2.1 (4)]

In the last years approx. 10 % of the new buildings have been constructed as low energy buildings class 2015. The decision to construct a building as a low energy class 2015 building are in principle voluntary, but many municipalities have designated specific areas or the hole municipal to low energy class 2015 buildings.

Low energy buildings class 2015 will be the requirement to all new buildings in 2015.

Buildings class 2020

Dwellings, student accommodation, hotels, etc. may be classified as a building class 2020 when the total demand for energy supply for heating, ventilation, cooling and domestic hot water per m² of heated floor area does not exceed 20 kWh/m²/year. [BR10: 7.2.5.2]

Offices, schools, institutions and other buildings not covered by 7.2.5.2 may be classified as building class 2020 when the total demand for energy supply for heating, ventilation, cooling, domestic hot water and lighting per m² heated floor area does not exceed 25 kWh/m²/year. [BR10: 7.2.5.3]

Class 2020 buildings must be built such that the design transmission loss does not exceed 3.7 W per m² of the building envelope in the case of single-storey buildings, 4.7 W for two-storey buildings and 5.7 W for buildings with three storeys or more. [BR10: 7.2.5.1 (1)]

Air changes through leakage in the envelope in class 20202 buildings must not exceed 0.5 l/s/m² of the heated floor area when tested at a pressure of 50 Pa. [BR10: 7.2.5.1 (5)]

In class 2020 buildings there are also tighter energy requirements to windows, roof lights, skylight domes, doors, hatches and gates.

There are also tighter requirements to the indoor climate in relation to daylight access, summer comfort and air quality.

The decision to construct a class 2020 building is voluntary. It is expected that municipalities will in the next years designate specific areas to class 2020 buildings, as they did with the class 2015 low energy buildings.

Class 2020 buildings are the Danish Nearly Zero Energy Buildings, nZEB in relation to the EPBD recast.

Energy requirements to extensions to building

The energy requirements to extensions to buildings are also used as requirements in case of change of use and in case of conversion associated with a change of use.

The provisions described in this section may be used for extensions, change of use and conversion associated with a change of use as an alternative to the basic provisions described for new building in the previous section. [BR10: 7.3.1 (1)]

“Change of use” means use for a different purpose that involves significantly higher energy consumption. Examples are:
– conversion of an outbuilding for accommodation.
– conversion of useable roof space for accommodation.

A new loft or new dwellings on flat roofs are extensions.

Table 7.3.2 Minimum thermal insulation in extensions

Table of U values	**W/m² K**	
Rooms/spaces heated to	T > 15°C	5°C< T < 15°C
External walls and basement walls in contact with the soil.	0.15	0.25
Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or heated to a temperature more than 5 K lower than the temperature in the room/space concerned.	0.40	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.10	0.15
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.10	0.15
Windows, including glass walls, external doors and hatches to the outside or to rooms/spaces that are unheated or heated to a temperature more than 5 K below the temperature in the room/space concerned (does not apply to ventilation openings of less than 500 cm²).	1.40	1.50
Roof lights and skylight domes.	1.70	1.80
Table of linear losses	**W/m K**	
Foundations around floors with floor heating.	0.12	0.20
Joint between external wall and windows or external doors and hatches	0.03	0.03
Joint between roof structure and roof lights or skylight domes.	0.10	0.10

Thermal insulation of building elements around rooms/spaces that are normally heated to a minimum of 15°C must have a heat loss of no more than as stated in the column marked temperature T > 15°C; the limit for building elements around rooms/spaces that are normally heated to more than 5°C and up to 15°C is as stated in the relevant column, see table 7.3.2. For windows, doors, hatches, roof lights and skylight domes, the U-values for the actual size apply. [BR10: 7.3.2]

The use of the U values and linear losses stated for extensions heated to no less than 15°C is subject to the total area of windows and external doors, including roof lights and skylight domes, glass walls and hatches to the outside comprising no more than 22 % of heated floor area in the extension. [BR10: 7.3.2 (2)]

In the case of a change of use, constructional factors may prevent full compliance. The shortfall in efficiency must be compensated for by other energy solutions. It may, for example, be difficult to comply with the requirements for linear loss for existing windows and foundations. By way of alternative, a corresponding amount of energy can be saved, for example by additional insulation or installation of solar heating, a heat pump or solar photovoltaic cells. [BR10: 7.3.2 (3)]

Structural alterations that increase energy consumption may be carried out provided that compensatory energy savings are made. This provision applies, for example, to fit new windows to a facade or roof. The reduced energy performance is compensated for by, for example, extra insulation, solar heating, a heat pump or solar photovoltaic cells. [BR10: 7.3.2 (4)]

Heat loss framework for extensions. U values and linear losses for extensions heated to no less than 15°C can be altered and window areas etc. increased, provided that heat loss from the extension is not greater than if the requirements of 7.3.2 were satisfied. However, insulation of the individual building elements must be at least on a par with the U values and linear losses specified in table 7.6. The heat loss framework in this context only covers the extension. However, previous heat loss through the covered part of the existing building may be allowed for in the heat loss framework. This does not apply to rooftop dwellings. [BR10: 7.3.3]

Energy requirements to existing buildings undergoing renovation

The energy requirements to existing buildings undergoing renovation are to the individual building elements. Buildings elements are both construction elements and windows in the building envelope and installation elements e.g. ventilation system, boiler or heat pump.

There is no specific energy requirement on building level to existing buildings undergoing renovation e.g. to the final energy consumption of the building. The rationale behind this is the huge variation in the design of existing building even if of the same type and constructed in the same period. The possibility to implement energy savings is thus very dependent on the conditions in the individual building and also functional and aesthetic requirements have high importance. The Danish energy requirement to existing buildings in case of major renovation is based on the sum of component requirements to the building elements in the building envelope and to the installation. If the renovation is performed as smaller tasks the same requirements are also valid.

For the construction elements in the envelope of existing buildings the regulation distinguish between:

- renovation of existing elements
- new elements.

The requirements to new construction elements in the building envelope are both in the case where an existing element is replaced by a new element and in the case where a new element is introduced without replacing an existing element. Example of replacements could be if the old roof is taken down (e.g. because of rot or after a fire) and a complete new roof is constructed. Example of new element being introduced could be if a light weight external wall element is replaced by cavity wall.

Table 7.4.2 (2) Requirements to insulation of the building envelope and linear losses in relation to existing buildings undergoing renovation.

Table of U values	**U value W/m² K**
External walls and basement walls in contact with the soil.	0.20
Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or heated to a temperature more than 5 K lower than the temperature in the room concerned.	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.12
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.15
External doors, roof lights and hatches.	1.65
Table of linear losses	**Linear loss W/m K**
Foundations.	0.12
Joint between external wall and windows or external doors and hatches	0.03
Joint between roof structure and roof lights or skylight domes.	0.10

n the case of replacement of elements or introduction of new elements the requirements to construction elements in the building envelope described in this section must be implemented, even if they may not be cost-effective.

In the case of renovation of existing construction elements in the building envelope considerations to cost-effectiveness can be taken. Examples of works where cost-effective insulation must be installed are:

- laying of new felt roof in the form of a new roof membrane or top felt on an existing roof
- a new tiled roof
- a new steel sheet roof on top of an old felted roof or a roof of fibre cement sheets

Requirements to new windows (described in this section) and to replaced or new installation elements (described in the next section) must be implemented, even if they may not be cost-effective.

Cost-effective energy savings

Table 1 in appendix 6 to BR10 lists solutions that are often cost-effective when carried out as part of a renovation or replacement. It only includes materials and labour for the energy-saving work and not, for example, costs of roofing, scaffolding or other costs that would be associated with completion if the work were not part of a renovation.

There may be conditions in a specific building which mean that insulation works are difficult to implement, so the work may not be viable. The same applies if, for example, very cheap energy in the form of one's own straw or wood is used. If the cost-effectiveness of the work is calculated as: (lifetime x savings)/investment < 1.33 the work is not cost-effective. The owner is therefore not obliged to implement the work. Table 2 in appendix 6 to BR10 lists the lifetime of different energy-saving works.

Constructional factors may render cost-effective compliance with the provisions impossible without detriment to moisture resistance. There may, however, be less extensive work whereby energy demand can be reduced. If so, it is this work which is to be carried out. Cavity wall insulation is an example of a measure that does not comply with the requirement. Compliance will require external retro-fitted insulation with a new weather shield. This may not be cost-effective in this particular case, whereas cavity wall insulation, which is less extensive work, may be highly cost-effective. Cavity wall insulation must therefore be installed. [BR10: 7.4.2 (3)]

Table 2 (BR10 appendix 6). Lifetimes that can be used to calculate cost-effectiveness:

Energy-saving measure	**Years**
Retro-fitted insulation to building elements	40
Windows with secondary windows and coupled frames	30
Heating systems, radiators and floor heating and ventilation ducts and fittings including insulation	30
Heat appliances etc., for example boilers, heat pumps, solar heating systems, ventilation units	20
Light fittings	15
Automation for heating and climatic control equipment	15
Joint sealing works	10

Window, rooflights, doors etc.

When replacing windows and rooflights, the energy gain through the window in the heating season must not be less than the figures in table 7.4.2 (4-5). Provisions which are expected to be introduced in 2015 and 2020 are also given in the table.

The energy gain is calculated as stated in Appendix 6 (in BR10). The requirement applies to a reference window 1.23 m x 1.48 m fitted with the manufacturer's standard pane.

If a window is in the form of a "Dannebrog" type window the requirement for the reference window is still used, provided the window is fitted with the manufacturer's standard pane. In commercial buildings or other buildings with high solar gain, window replacement can then be combined with, for example, external solar screening or solar control glass. There is no restriction in using noise-reducing and other functional glazing in connection with window replacement, provided the reference window using the manufacturer's standard pane complies with the requirement of energy gain.

The surface temperature of window frames in external walls must not be lower than 9.3°C. The provision for surface temperature of window frames in external walls will be re-assessed up to 2015. [BR10: 7.4.2 (6/8)]

Table 7.4.2 (4-5) Requirements to energy gain through windows and rooflights in kWh/m²/year.

Year	2010	2015	2020
Energy label	C	B	A
Windows	-33	-17	0
Rooflights	-10	0	10

When replacing skylight domes after 1 January 2015, the U value of the dome including frames must not exceed 1,40 W/m²K. In 2020 this is tightened to the U value must not exceed 1.20 W/m²K.

In 2020 external doors and hatches must not have a U value exceeding 0.80 W/m²K. Gates must have a maximum U value of 1.40 W/m²K. External doors with glazing must not have a U value exceeding 1.00 W/m²K or an energy gain through the door during the heating season of less than 0 kWh/m² per year.

Energy requirements to installations

The energy requirements to installations apply to both new buildings and to existing buildings undergoing renovation.

Heating systems

Heating systems must be designed, built, commissioned and handed over as required by DS 469, Heating and Cooling systems. In the new version to be in force primo 2013 DS 469 also includes requirements to the control of heating and cooling systems inclusive of requirements time control of heating and cooling supply, for individual room temperature control of heating and cooling to the rooms and for supply temperature control in central heating and cooling systems. [BR10: 8.2 (2)]

Electric and air heating systems in buildings must incorporate automatic regulation of heat transfer according to the heat demand in each individual room. The system must also be fitted with time and temperature control of heat transfer to the rooms. [BR10: 8.2 (3)]

Cooling systems and heat pumps must incorporate automatic regulation of the cooling or heating output according to the demand. Cooling systems must also be fitted with time and temperature control of cooling output to the rooms/spaces. [BR10: 8.2 (4)]

8.2(5) Heating systems must be designed and built for energy-efficient operation. It must also be ensured that simultaneous cooling and heating do not occur in the same room/ space. [BR10: 8.2 (5)]

Domestic water systems supplied by a domestic ventilation heat pump must have a minimum COP (coefficient of performance) at the draw-off point of 3.1. [BR10: 8.2 (7)]

Circulating pumps in heating, hot water, geothermal heating and cooling systems must be A rated or must comply with the corresponding energy requirements. The energy requirements for A rated pumps are shown in Europumps Industry Commitment to Improve the Energy Performance of Stand-Alone Circulators, January 2005. (The provision will be updated in relation to the new eco design criteria for pumps.) [BR10: 8.2 (8)]

Installations must be insulated against heat loss and condensation in accordance with DS 452, Code of practice for thermal insulation and technical service and supply systems in buildings. [BR10: 8.1 (9)]

DS 452 refers the insulation classes in EN 12828 to set the insulation requirements to the different parts of heating, hot water and ventilation systems. DS 452 is under revision. As result of the revision the requirement to insulation is in general expected to be tightened by one insulation class.

Ventilation

Single-family houses may be ventilated by natural or mechanical ventilation. [BR10: 6.3.1.2 (2)]

In domestic buildings other than single-family houses the background air changes in the housing unit must be provided by a ventilation installation with heat recovery, forced air supply in habitable rooms and extractors from bathrooms, sanitary conveniences, kitchens and utility rooms. In summer, air supply may be replaced by fresh air supply through windows, fresh air vents and the like. [BR10: 6.3.1.2 (3)]

In domestic buildings other than single-family houses with natural ventilation, demand-controlled ventilation may be used provided that air changes by this means will be no lower than 0.3 l/s per m². [BR10: 6.3.1.2 (4)]

Exhaust of 20 l/s from kitchens must be possible, and a minimum flow of 15 l/s from bathrooms and rooms containing sanitary conveniences. Exhaust of 10 l/s must be possible from separate rooms containing sanitary conveniences, utility rooms and basement rooms. [BR10: 6.3.1.2 (5)]

Rooms in childcare institutions must be ventilated by ventilation installations comprising both forced air supply and exhaust and heat recovery. The ventilation must ensure a good, healthy indoor climate. Fresh air supply and extraction must be no less than 3 l/s/child and no less than 5 l/s/adult plus 0.35 l/s/m² floor area. At the same time, it must be ensured that the CO_2 content of the indoor air does not exceed 0.1% for extended periods. If a ventilation system with demand-controlled ventilation is used, the specified air volumes may be deviated from when there is reduced demand. [BR10: 6.3.1.3 (1)]

Teaching rooms in schools etc. must be ventilated by ventilation installations comprising both forced air supply and exhaust and heat recovery. Fresh air supply to and extraction from normal teaching rooms must be no less than 5 l/s/person plus 0.35 l/s/m² floor area. At the same time, the CO2 content in the indoor air must not exceed 0.1% for extended periods. If a ventilation system with demand-controlled ventilation is used, the specified air volumes may be deviated from when there is reduced demand. The ventilation during the hours of use may, however, not be less than 0.35 l/s per m² floor area. Where special constructional allowances are in place, for example greater room volumes per person, the use of several extraction options, including cross-ventilation options, the requirement for mechanical ventilation may be waived provided that a comfortable, healthy indoor climate is maintained. [BR10: 6.3.1.3 (2)]

Ventilation installations must incorporate heat recovery with a dry temperature efficiency of no less than 70%. The heat recovery unit can be combined with a heat pump for heat recovery. This must have a minimum COP (coefficient of performance) of 3.6 in heating mode. [BR10: 8.3 (6)]

Ventilation installations that supply one dwelling must incorporate heat recovery with a temperature efficiency of no less than 80%. [BR10: 8.3 (8)]

For ventilation installations with a constant air volume, the power consumption for air movement must not exceed 1800 J/m³ external air. For installations with a variable air volume, the power consumption for air movement must not exceed 2100 J/m³ external air at a maximum output and at maximum pressure drops. For exhaust systems without mechanical air supply, the specific power consumption for air movement must not exceed 800 J/m³. "Power consumption for air movement" means the total power consumption per m^3 of air moved, calculated from air inlet to exhaust outlet. Power consumption for air movement can be calculated for each individual installation or jointly for several installations in a building. [BR10: 8.3 (9)]

For ventilation installations with a constant or variable air volume and heat recovery supplying a dwelling, the power demand for air movement must not exceed 1000 J/m³ for the mode of operation with the maximum pressure drop. The installation must be provided with power via a connection that allows power consumption to be measured. [BR10: 8.3 (10)]

Equipment for humidifying intake air may only be installed if this is warranted by reasons of safety, production, preservation or health. [BR10: 8.3 (11)]

Ventilation installations must be installed, commissioned and handed over as stated in DS 447, Code of practice for mechanical ventilation installations. These provisions also apply to the construction of ventilation installations in existing buildings and to the renovation of installations. The requirements for ventilation installations also apply to single-family houses. [BR10: 8.3 (3)]

Daylight

Workrooms, occupiable rooms in institutions, teaching rooms, dining areas, hereinafter called "workooms etc.", and habitable rooms must have sufficient daylight for the rooms to be well lit. Windows must be made, located and, where appropriate, screened such that sunlight through them does not cause overheating in the rooms, and such that nuisance from direct solar heat gain is avoided. [BR10: 6.5.2 (1)]

In workrooms etc., the daylight can usually be taken to be sufficient if the glazed area of side lights corresponds to a minimum of 10% of the room floor area or, in the case of rooflights, no less than 7% of the room floor area, assuming that the light transmittance of the glazing is no less than 0.75. The 10% and 7% are guidelines assuming a normal location of the building and a normal layout and fitting out of the rooms. The glazed area must be increased in proportion to any reduction in light transmittance (for example solar control glazing) or reduced light ingress to the windows (for example nearby buildings). Daylight may similarly be deemed to be adequate when calculation or measurement can demonstrate that there is a daylight factor of 2% at the workplaces. When determining the daylight factor, account must be taken of actual conditions, including the design of the windows, the light transmittance of the surroundings. See By og Byg (SBi) Guidelines 203, "Beregning af dagslys i bygninger" [Calculation of daylight in buildings] and SBi Guidelines 219, "Dagslys i rum og bygninger" [Daylight in rooms and buildings].

Electric lighting

Workrooms etc. and shared access routes must have artificial lighting as necessary. In the types of workrooms covered by the DS 700 series, Artificial lighting in workrooms, these standards must be used. [BR10: 6.5.3 (1)]

Workrooms etc. and shared access routes must be provided with energy-efficient lighting. If there is sufficient daylight, workrooms etc. and shared access routes must be fitted with daylight control. Energy-efficient lighting is luminaires with an efficiency for general lighting of over 50 lm/W and for effect working lamps of over 15 lm/W. [BR10: 6.5.3 (2)]

Workrooms etc. with occasional usage and shared access routes must be provided with movement sensors. The use of movement sensors may be omitted if switching off a light may lead to a risk of accidents, or if the luminaires are not suitable. This provision also applies to bathrooms and rooms containing sanitary conveniences associated with workrooms etc. [BR10: 6.5.3 (3)]

Lighting systems in workrooms etc. must be divided into zones and be available for use as appropriate according to daylight conditions and activities. [BR10: 6.5.3 (4)]

Boilers

On CE marking, oil-fired boilers must have a fuel use efficiency of no less than 93% at full load and 98% at part load. [BE10: 8.5.1.4 (2)]

On CE marking, gas-fired boilers must have a fuel use efficiency of no less than 96% at full load and 105% at 30% part load. [BE10: 8.5.1.4 (3)]

Boilers stoked by coal, coke, bio-fuels and biomass must have a useful efficiency of no less than boiler class 5 in DS/EN 303-5, Central heating boilers. [BE10: 8.5.1.4 (4)]

Boilers for natural gas or fossil oil must not be installed in new buildings. Exemption from the requirement is possible:

- if buildings in the specific area in relation to the heat planning can get natural gas,
- if all other alternatives are unsuitable,
- if local development plans for district heating.

Replacement of oil burners in existing buildings are not allowed from 2014.

Solar heating systems

On new buildings or on renovation of buildings outside existing district heating areas, in which the expected daily hot water consumption exceeds 2000 litres, solar heating systems must be provided which can meet an energy demand corresponding to the hot water consumption under normal operating conditions. The system must be designed to meet a demand corresponding to no less than 95% of the demand for hot water from May up to and including September. Hot water consumption must be based on SBi Guidelines 213. [BR10: 8.6.2 (2)]

Heat pumps

For liquid/water heat pumps (geothermal heating systems), the system must have a nominal power factor no less than as stipulated by the Danish Energy Authority's energy labelling scheme depending on size and whether the system supplies floor heating:

Size	Nominal power factor
0 – 3 kW	3.0
3 – 6 kW	3.6
> 6 kW	3.7

If the producer instead have documentation of the SCOP, the nominal power factor is calculated as 0,85 x SCOP. [BR10 8.6.4(4)]

For liquid/water heat pumps (geothermal heating systems), the system must have a nominal power factor of no less than as per the Danish Energy Authority's energy labelling scheme depending on size and whether the system supplies radiators:

Size	Nominal power factor
0 – 3 kW	2.6
3 – 6 kW	2.8
> 6 kW	3.0

If the producer instead have documentation of the SCOP, thenominal power factor is calculated as 0,85 x SCOP. [BR10 8.6.4(5)]

Air/water heat pumps must have a nominal power factor of no less than 3.2 as per the Danish Energy Authority's energy labelling scheme when connected to floor heating. Similarly, air/water heat pumps must have a nominal power factor of no less than 2.7 when connected to radiators.

If the producer instead have documentation of the SCOP, thenominal power factor is calculated as 0,90 x SCOP. [BR10 8.6.4(6)]

Air/air heat pumps must have an efficiency in heating mode corresponding to a SCOP of no less than 3.4 in accordance with DS/EN 14511, corresponding to an A label as per the EU energy labelling of household airconditioners. [BR10 8.6.4(7)]

For heat pumps not covered by 8.6.4(4)-(6), the manufacturer must state the COP (coefficient of performance) and standby consumption. [BR10 8.6.4(8)]

Small-scale CHP plants

These provisions apply to small-scale CHP plants (combined heat and power) with an output not exceeding 120 kW. [BR10: 8.5.1.2 (1)]

CHP plants must be designed and built to achieve energy-efficient operation. The overall efficiency including heat production must be no less than 80% for installations using Sterling motors, piston motors or fuel cells. For other types of heat and power producing systems, such as thermoelectric systems, the requirement is deemed to be met if the thermal efficiency plus 2.5 times the electrical efficiency together exceeds 90%.[BR10: 8.5.1.2 (2)].

Danish energy calculation tool

The Danish energy calculation tool is described in: "SBi Direction 213: The Energy Demand of Buildings - PC application and guidelines for calculations - Guidelines for Calculations". The PC application includes a calculation core mandatory to be used in relation to calculation of energy demand in new building in relation to the Danish Building Regulations and in relation to energy labeling of new and existing building.

Part of the specification of the energy calculation tool is in appendix 6 in BR 10. Example of this is the energy factors to be used, see table. The decrease of the factor for district heating and electricity is mainly caused by the expected increase of wind power in the Danish energy supply system the coming years.

Energy factors to be used in relation to calculating the energy demand of buildings.

Energy type	2010	2015	2020
District heating	1,0	0,8	0,6
Other heating	1,0	1,0	1,0
Electricity	2,5	2,5	1,8

Heat supplied from solar heating systems is subtracted in the heating demand of the building. Electricity from solar panels, PV and from wind power is subtracted in the electricity demand of the building for operation of building systems. In the past (until 1. January 2013) the maximum annual subtraction from PV and wind power was only limited by the total annual electricity consumption of the building all inclusive e.g. office and household equipment and plug loads. The result of this can be a negative figure for electricity for building operation. Today the maximum annual subtraction from PV and wind power is limited to the annual electricity demand for building operation and the monthly subtraction is limited to the total monthly electricity consumption of the building all inclusive.

The Danish energy calculation tool prescribes normatively a room temperature of minimum 20 C in ordinary heated buildings: dwellings, office, institutions etc. Very few - if any - designer uses an internal temperature over 20 C when they calculate the energy demand for a new building in relation to the energy frame requirement in BR10. About actual energy consumptions and room temperatures, see later chapter.

The design temperatures for heating are stated in DS 418 and DS 469 to be:

Internal:	20 C
External:	-12 C

As a new development DS 469 is extended to also cover cooling systems. In the new version of DS 469 the design temperatures for cooling are:

Internal:	25 C
External:	25 C

As far as possible, the methodology in the Danish calculation tool is based on European standards. The calculations are carried out on a monthly basis.

Heat demand

The heat demand is calculated in accordance with EN ISO 13790. Determining the heat demand requires a number of factors to be taken into consideration: the use of solar screening; the length of the heating season; actual recovery of part of the heat loss from installations such as boilers, as well as heating of supply air to attain the necessary supply air temperature.

Cooling requirements

Cooling requirement is also calculated in accordance with ISO 13790. Solar screening is taken into consideration as well as the cooling effect of extra ventilation in hours of use and at night in hot summer periods.

Heat loss from installations

The heat loss from pipes, vessels, district heating units, ventilation ducts, etc. is in accordance with DS 452. The heat loss from pipes is calculated based on EN 15316, parts 2.3 and 3.2. Determination of the heat loss takes into account the temperature of the pipes and of the surroundings. Heat loss from heating pipes within the building envelope is not included, provided that the temperature of the pipes or water is regulated according to heat demand in the building or to the outside temperature. The heat loss from ventilation ducts and ventilation units within the building envelope is also excluded. Ventilation ducts and ventilation units outside the building envelope are calculated in the same way as the building envelope, as they are taken to be heated to normal room temperature. Heat loss from pipes supplying domestic hot water that cools down between flows is not included. The guidance regarding waiting time for hot water in DS 439 must be followed.

Boilers
The heat loss from boilers and the electrical energy consumption of the boiler is determined for each month on the basis of the actual conditions. Determination of loss from boilers takes account of factors such as efficiency, heat loss to the surroundings, the control of boiler temperature, the production of domestic hot water, as well as the electrical energy consumption of the blower and of automatic controls. It is assumed that the boiler is turned off in summer if the consumption of domestic hot water is covered in another way, such as by solar heating or by domestic hot water pumps. Data for boilers is calculated as specified in EN 15316 part 4.1 method II, and part 3.3.

Heat pumps
The electrical energy consumption of heat pumps is determined on the basis of the total efficiency, taking account of the heat source and sink temperature differences, as well as consumption for auxiliary equipment, including pumps, fans, electric heating elements and automatic controls. The calculation for heat pumps is to be performed in accordance with the relevant sections of EN 15316 part 4.2, even though this standard specifies a method by which a whole year is calculated jointly.

Solar heating
The contribution of solar heating to domestic hot water is determined for each month on the basis of the actual design of the system, including the size, orientation and slope of the solar panels. In addition, the electrical energy consumption for pumps and automatic control is determined. The calculation of the contribution of solar heating, including its contribution to space heating, must be specified on the basis of EN 15316 part 4.3.

Pumps
The electrical energy consumption of pumps is determined on the basis of the nominal output of the pumps, the running time of the installation and the controls. All pumps in the heating installations must be included in the calculations, including pumps on the boiler, pumps for the heating and circulation of domestic hot water, and pumps used for cooling.

Fans
The electrical energy consumption of fans is determined on the basis of the electric power and the operation hours of the installation. In systems with varying flow, the average electric power is used in the calculations. In hybrid ventilation systems, it can be taken ?? that part of the ventilation is natural, provided this can be documented.

Cooling machines
The electricity consumption of cooling machines is determined on the basis of the overall efficiency of consumption for auxiliary equipment, including pumps, fans, electric heating elements and automatic controls.

Lighting
The electricity consumption for lighting is calculated in accordance with the relevant parts of EN 15193-1.

Solar cells
The calculation for solar cells is based on EN 15316 part 4.6.

Consumption of other energy to operate the building
For practical reasons, operating a building involves some minor uses of electricity that need not be included here. These include electrical energy consumption for elevators; pumps in pressure increasing systems for domestic

water or sprinklers; window opener motors; pumps for heat recovery plates in ventilation installations; and motors for rotating heat exchangers, convector fans, small bathroom fans and extractor hoods that only run for a small part of the time that the building is in use. In addition, there is electricity consumption for central automation systems (CTS) and emergency lighting. The calculation must include electrical energy consumption in any automatic components that are specific to a boiler, a district heating converter, a solar heating system, a heat pump or the like.

Danish heat planning act

The objective of the Danish heat planning Act is to promote the most socio-economic and environmentally friendly utilization of energy for heating buildings, supplying them with hot water and reduce the dependency of the energy system on oil. In agreement with the objectives mentioned, the supply of heat shall be organised with a view to promoting the highest possible degree of cogeneration of heat and power. For the purpose of the Act, collective heat-supply plant means any undertaking that operates the below-mentioned plants with the object of supplying energy for heating buildings and supplying them with hot water:

1) plants producing and transmitting other inflammable gasses than natural gas;
2) plants for transmitting heated water or steam from combined heat and power plants, waste incineration plants, industrial enterprises, geothermal installations, etc.;
3) district heating supply plants, solar heating plants, waste-incineration plants, etc. , including combined heat and power plants with an electric effect not greater than 25 MW;
4) block heating stations with heat generating capacity exceeding 0.25 MW, including combined heat and power plants with an electricity output not greater than 25 MW.

It is the duty of each district council, in cooperation with the supply companies and other involved parties, to prepare a plan for the supply of heat in the municipality. The Minister for Environment and Energy may direct that specific preconditions shall form the basis of the planning for the municipal heat supply, including the basis for decisions made according to this Act.

Each district council shall approve projects for establishing new collective heat supply plants or for major alterations of existing plants. Producers and suppliers of piped energy as well as consumers shall upon request furnish the Minister for Environment and Energy and any relevant district council with any information deemed necessary for planning the supply of heat in the municipality. After consultation with the municipal authorities, the Minister for Environment and Energy may establish regulations on planning pursuant and determine how cases shall be dealt with.

Each district council shall ensure that any project for a collective heat supply for each plant explores the following possibilities:

1) that it supplies a specified area with energy for heating purposes to a specified extent;
2) that it is designed so as to ensure the most economical utilization of energy;
3) that its operations are coordinated with those of other plants;
4) that any plant over 1 MW be converted to combined heat and power production.

5) A district council may order an existing heat-supply plant to implement an authorised project before a certain deadline.

If it is a precondition in an authorised project pursuant, the district council can require a collective heat-supply plant:

1) to organize its production facilities in such a way that specified types of energy can be used in the production and
2) to use certain types of energy in the production to a specified extent.

A district council shall follow developments in connections to the collective heat-supply system in its municipality. In this regard, an undertaking that supplies district heating and natural gas shall present to the district council every other year, a report on connections to the plant.

If it is presupposed in an authorised project for a collective heat-supply plant, at the latest when granting planning permission, the district council may direct that when new buildings are taken into use they shall be connected to the plant. The district council shall approve the conditions for the connection.

If presupposed in an authorised project for a collective heat-supply plant, the district council may direct that existing buildings shall be connected to the plant within a certain time limit, i.e. with reference to the natural pace of replacement for existing heating installations. The district council shall approve the terms for the connections.

A district council may require that the owner of a building can be required to be connected to a collective heat-supply plant, and pay a contribution to the plant, when it is possible for the building to receive its supply of heat from the said plant.

In the event that expropriation of property is essential to establish the pipelines and heat-supply equipment needed for an approved collective heat supply plant, the following may be implemented:

1) the proprietary rights in land, buildings and in fixed installations permanently attached to land or buildings and any appurtenances to such land and buildings may be acquired;
2) the owner’s right of disposal of such real property may be permanently or temporarily restricted, or the right to disposal of real property for special purposes may be acquired;
3) rights over real property may be permanently or temporarily acquired or annulled, or limitations can be made in these areas.

The income brackets when selling hot water, steam or gas to domestic consumers, which are connected to collective heat network, industrial enterprises, and combined heat and power producers with capacity exceeding 25 MW as well to geothermal plants, also include necessary expenses for fuel, wages, and other operational costs, research activities, administrative and energy delivery costs as well as costs related to public service obligations, financing expenses and costs of the previous period, which accrued due to investments implementing or developing the energy networks.

Income brackets may include operational depreciations and appropriations for reinvestments and interest rate of invested capital with the approval of the Energy Regulatory Authority. The Minister of Environment and Energy may establish rules on distribution of cost between electricity production and heat production on biomass-fuelled combined heat and power plants. The Minister may establish rules on a maximum price for hot water or steam from waste incineration plants and may establish rules on distribution of cost between electricity production and heat production on waste incineration plants.

The collective heat supply plants can establish different prices for separate consumers, groups of consumers and geographically delimited areas. The Minister of Environment and Energy may establish rules on prices for connection of buildings to a collective heat supply plant. Where technically feasible, the consumer shall start to pay for the utilized hot water, steam and gas, except for natural gas, to the producer according to the meter, despite of whether the customer is the owner or a lessee.

Reference buildings

The Danish reference buildings are from the Collection of Examples on Energy Efficiency in Buildings on www.bygningsreglementet.dk.

The rule in BR10: 7.2.3 (3) on proportional addition to the energy frame for new building in the case of buildings or building sections whose requirements include, for example, a high level of lighting, extra ventilation and high consumption of domestic hot water, or which are used for extended periods, or buildings with high ceilings excludes the need for additional reference buildings compared to the reference office building.

The rule in BR10: 7.4.2 and BR10 appendix 6 on cost-effectiveness of the energy saving work in existing buildings undergoing renovation excludes the need for additional reference buildings compared to the reference office building.

The reference buildings for existing buildings are as they look today without extensions or renovations. Typical improvements are only adding of double glazing in windows and a little additional insulation on loft's.

The reference buildings are described in further details in the appendix.

Summary of the new reference buildings.

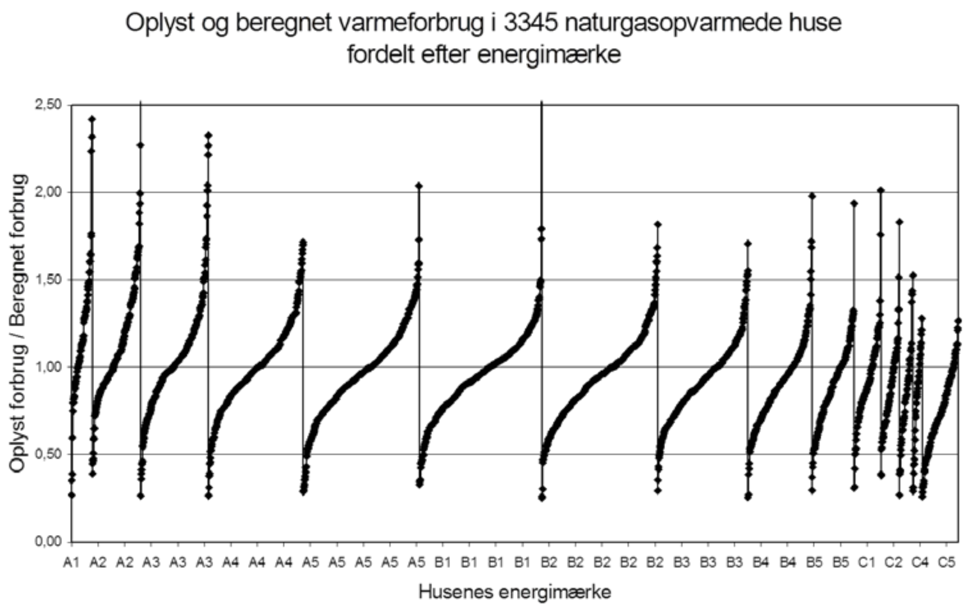
Building type	Heat supply	Gross floor area m^2	Storey No.
Single family house	District heating Heat pump	150	1
Multifamily house	District heating	1080	3
Office building	District heating	3283	4

Summary of the reference buildings for existing buildings.

Building type	Heat supply	Gross floor area m^2	Storey No.
Single family house, 1930	District heating Natural gas Heat pump	103	1
Single family house, 1960	District heating Natural gas Heat pump	108	1
Multifamily house, 1930	District heating	1664	4
Multifamily house, 1960	District heating	3640	4
Office building, 1960	District heating	3283	4
Office building, 1980	District heating	3283	4

Actual energy consumption and savings

Room temperature is often lower in poor insulated buildings and higher in new well insulated buildings.



Measured consumption and calculated energy demand in 3345 single-family houses with natural gas heating related to the energy label for the house. A1 is best and C5 I poorest. Energy label system 2005.

In new houses and in other new buildings the room temperature is often higher than 20 C. In houses this is normally the case in the living room when it is in use. In the bedrooms it is more individual if it is heated or not. The average room temperature might be 21 C or even 22 C in average in new well insulated building in the heating season.

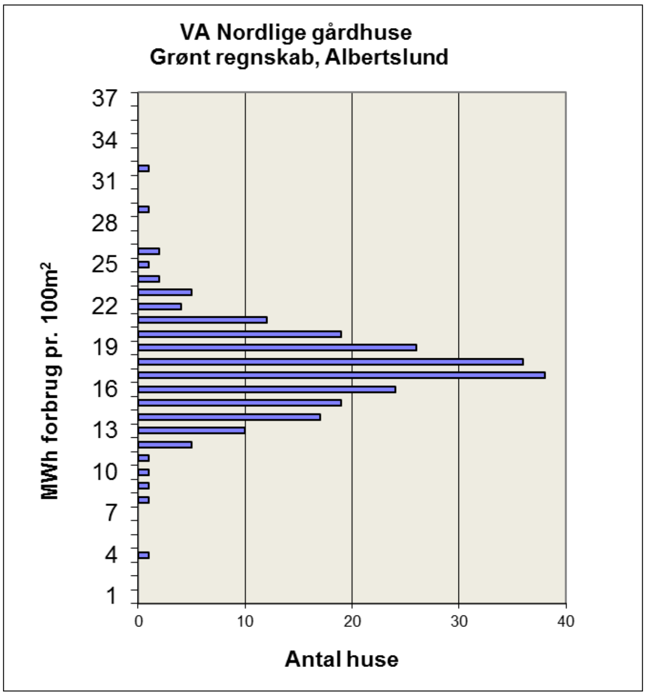
In existing houses with poor insulation the room temperature is often lower than 20 C or some rooms are unheated to reduce the heating costs. If houses are improved to better insulation level or to higher energy efficiency it is likely the users will partly convert the energy savings to improved thermal comfort by raising the room temperature. The achieved energy savings will thus be lower.

In the evaluation of the cost-optimal level of the energy requirements to new buildings in BR10 an internal temperature of 20 C is used. It compensates both the higher external temperature in relation to the different in external temperature between last years and DRY and the higher room temperature of found in new, well insulated buildings.

In existing single-family houses build before the energy crises in 1973 a lower internal temperature of 19 C is used to compensate both the lower internal temperature and the reduction in saving due to raise in room temperature in relation to the implementation of the energy saving measures.

In existing multifamily houses and in offices, institution etc. and internal temperature of 20 C are used as in the new buildings.

There are also large differences in energy consumption of individual houses and dwellings dependent on user habits. This is of course relevant for estimating the financial of energy saving measures for the individual house or dwelling - but might not matter when setting the general requirements in building regulations.



Heating consumption in identical semi-detached houses heated by district heating.

Tabel 20. Der er en signifikant sammenhæng mellem varmeforbrug (incl. opvarmning af varmt vand) og husstandens samlede antal bade. I forhold til badevaner5 har vi ganget oplysning om gennemsnitlig ugentligt antal bade pr. person med antallet af personer i husstanden (Gamma=0,211, p=0,004).

Antal bade pr. uge	Småforbruger	Normalforbruger	Storforbruger	I alt
Under 8	52%	23%	22%	100%
8 – 12	24%	39%	37%	100%
12 – 18	31%	37%	32%	100%
Over 18	24%	31%	45%	100%

Behaviour in relation to bathing and actual heating consumption.

Tabel 17. Der er stærk signifikant sammenhæng mellem, om man selv mener, at man sparer på varmen, og hvilken kategori af varmeforbrugere man tilhører. (gamma= 0,348, signifikant med p=0,000).

Sparer du/I på varmen?:	Ja, meget	I nogen grad	Normalt ikke
Småforbrugere	41%	25%	23%
Normalforbrugere	36%	34%	15%
Storforbrugere	23%	41%	62%
I alt	100%	100%	100%

Energy saving viewpoint and actual heating consumption.

Costs

All costs are in 2012 prices.

Discount rate

In accordance with the Delegated Regulations (EU) No. 244/2012 a discount rate of 3,0 % p.a. net are in general used to convert the prices and costs from other years to 2012 price level. The same discount rate is used in relation to macro-economic and financial calculations. The discount rate is exclusive of inflation.

The discount rate reflect the financing costs of the actual investments in question or the economic benefit of alternative investments of the same money. In some cases the discount rate also includes a "safety" factor based on the viewpoint: It is more safe to delay the investment and see how the situation and solutions develops - than to invest now. This is a good approach in most cases where the investment can be done at any time later - but it is not a good solution in case of adding energy efficiency to a building only being constructed or renovated one-off.

The housing mortgage interest rate is in 2012 for new mortgage 3,0 - 3,5 % p.a. and the commercial mortgage interest rate is approximately 1,0 % p.a. higher. The mortgage interest rate is subtracted in the taxation by 27,5 % for private persons e.g. in housing and by 40 % for commercial business. With an inflation rate of 2,0 % p.a. the resulting net interest rate is then 0,5 - 1,0 % p.a. The Danish national debt in 2012 has an interest rate of 1,5 - 2,0 p.a. If a safety factor should be added it should be negative to encourage the implementation of the energy efficiency when one-off possibly. As an alternative to the discount rate required in the Delegated Regulations Denmark also use an alternative discount rate of 1,0 % p.a. in relation to the calculation of cost-optimal levels in this report.

Mortgage and inflation are from Danish Statistics and from "Assumptions for socio-economic analyses in the energy sector - Tables September 2012" by the Danish Energy Agency. The forecast in the assumptions are based on the latest prices from IEA in World Energy Outlook and an expectation of the development in the dollar exchange rate.

Energy prices

The macroeconomic energy prices and price trends are extracted from: "Assumptions for socio-economic analyses in the energy sector - Tables September 2012" by the Danish Energy Agency. The tables includes projections for each of the years 2012 - 2035. The projection is in this report converted to a trend in % p.a. for all the years represented in the tables.

The financial energy prices are from the statistics of the Danish Energy Regulatory Authority, 3. quarter 2012. The price trends on the financial energy prices are established from the price trend on the macroeconomic energy prices assuming unchanged energy taxes. The financial prices are inclusive of energy taxes, but exclusive of VAT. All consumers pay energy taxes for heating and electricity to operation of buildings. Only commercial productions are exempted from energy taxes. VAT will be added separately where relevant.

Natural gas

Macroeconomic

Gas price 2012:	215 DKK/MWh
Price increase the coming years:	0.60 % p.a.

Figures from Assumptions for socio-economic analyses, Table 6.

Financial

Gas price, 2012:	683 DKK/MWh
Price increase the coming years:	0.19 % p.a.

The variation in natural gas price for different consumers are limited.

District Heating

Price for consumption of energy. Additional cost for connection and subscription are not included.

Macroeconomic

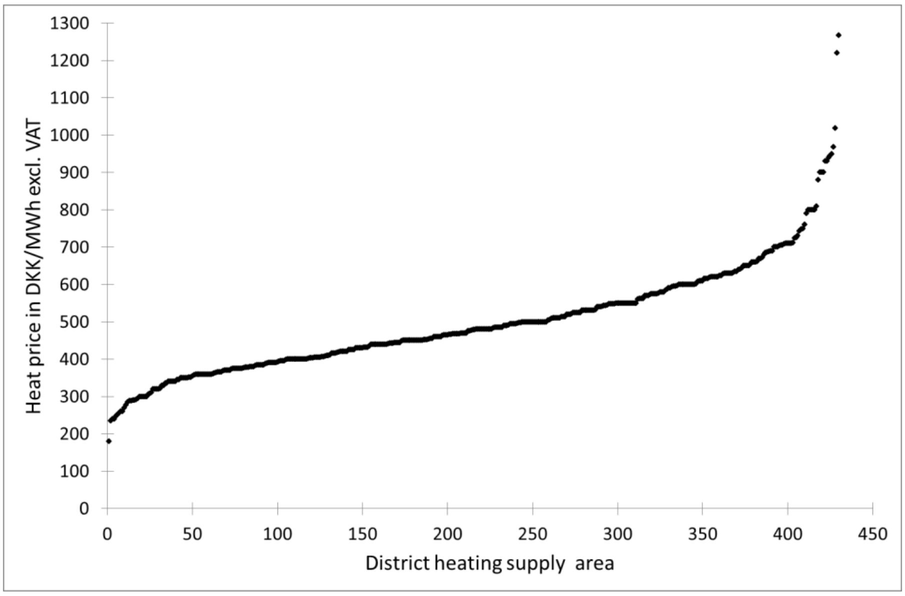
District Heating price 2012:	241 DKK/MWh
Price increase the coming years:	0.29 % p.a.

Figures from Assumptions for socio-economic analyses, Table 7.

Financial

District heating price, 2012:	500 DKK/MWh
Price increase the coming years:	0.14 % p.a.

The variation in the district heating price for different supply areas is large, see figure. The variation in the district heating price for different consumers in the same supply areas is limited.



Electricity

Macroeconomic

Electricity price, private household, 2012:	568 DKK/MWh
Price increase the coming years:	0.95 % p.a.
Electricity price, commercial, 2012:	547 DKK/MWh
Price increase the coming years:	0.98 % p.a.

Figures from Assumptions for socio-economic analyses, Table 7

Financial

Electricity price, private household, 2012:	1,760 DKK/MWh
Price increase the coming years:	0.31 % p.a.
Electricity price, private house, electric heating, 2012:	1,640 DKK/MWh
Price increase the coming years:	0.33 % p.a.
Electricity price, commercial, 2012:	1,600 DKK/MWh
Price increase the coming years:	0.34 % p.a.

CO_2 emission

The CO_2 emissions trend are extracted from: "Assumptions for socio-economic analyses in the energy sector - Tables September 2012" by the Danish Energy Agency and converted to a trend in % p.a. in the same way as done with the energy prize trend.

Natural gas

Decrease in CO_2 emission the coming years: 0.00 % p.a.

Figures from Assumptions for socio-economic analyses, Table 8.

District Heating

Decrease in CO_2 emission the coming years: 1.83 % p.a.

Figures from Assumptions for socio-economic analyses, Table 9.

Electricity

Decrease in CO_2 emission the coming years: 5.40 % p.a.

Figures from Assumptions for socio-economic analyses, Table 9.

CO_2 emission costs

The CO_2 emissions cost and trend in costs are extracted from: "Assumptions for socio-economic analyses in the energy sector - Tables September 2012" by the Danish Energy Agency and adjusted to the EU minimum stated in the Delegated Regulation before converted to a trend in % p.a. in the same way as done with the energy prize trend, see table below.

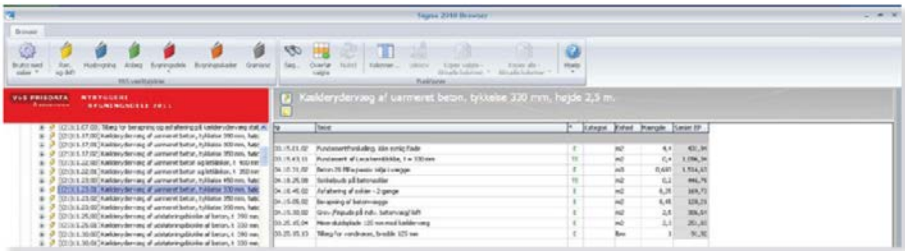
CO_2 emission costs used in the calculations. EU figures from Delegated Regulation. DK figures from Assumptions for socio-economic analyses table 10.

Year	EU min Euro/Ton	EU min DKK/Ton	DK DKK/Ton	Used price DKK/Ton
2012	21,23	159	48	159
2013	21,23	159	63	159
2014	21,23	159	79	159
2015	21,23	159	94	159
2016	21,23	159	108	159
2017	21,23	159	122	159
2018	21,23	159	136	159
2019	21,23	159	151	159
2020	21,23	159	165	165
2021	21,23	159	171	171
2022	21,23	159	177	177
2023	21,23	159	182	182
2024	21,23	159	188	188
2025	37,15	279	193	279
2026	37,15	279	199	279
2027	37,15	279	204	279
2028	37,15	279	210	279
2029	37,15	279	215	279
2030	53,08	398	221	398
2031	53,08	398	226	398
2032	53,08	398	232	398
2033	53,08	398	237	398
2034	53,08	398	243	398
2035	53,08	398	248	398

CO_2 emission costs, 2012:	159 DKK/ton-CO_2
Increase in CO_2 emission costs the coming years:	4.12 % p.a.

Construction and renovation costs

Construction and renovation costs are in general from V&S Price Data if other sources are not mentioned. The V&S Price Data is operated by Byggecentrum and used by most architects, engineers and contractors to calculations expected cost of building projects. The prices include material and labour costs for a large number of typical works in relation to construction of new buildings and in relation renovation of existing building. The prices are exclusive of building site establishment and operation and exclusive of eventual costs for scaffold. The prices are inclusive of waste, basic costs and profit. The prices are for Zealand outside Copenhagen as an average for the Danish building construction market. The prices are 5 % higher in Copenhagen and 15 % lower in the North of Jutland. The prices in V&S Price Data are exclusive of VAT. Prices are updated annual.



The V&S Price Data includes several databases, where four are relevant for this analysis:

Construction of new buildings:	Buildings
	Building elements
Renovation of existing buildings:	Buildings
	Building elements

Each of the price databases are divided in section. In the case of the databases for construction or renovation of buildings the database is divided in sections according to the SfB-system for numbering of building elements. The sections are:

1. Building basis
2. Primary building elements
3. Supplements
4. Surfaces
5. Heating and ventilation systems
6. Electric and mechanical systems
7. Fixtures
8. Other building elements
10. Site
11. Design

Example of calculating the initial investment for different thickness of roof insulation in an existing single-family house is in the tables on next page. The first table show the adding of cost for the different works included and the second shows the relation between total size of the work and the costs per m^2 of construction area.

In relation to elements as e.g. windows, small ventilation units and boilers it is impossible to find relevant product that don't fulfil the minimum requirements in the building regulations. If on the market e.g. via low price web shops the products are typically also poor in quality from other viewpoints. It is thus impossible to establish the reference costs and net present value for these types of products in relation to identify the cost-optimal level.

In 2009 when the cost-benefit analysis for the 2010 energy regulation was performed the additional cost for windows with energy efficient framing and triple-layer low-emission glazing was estimated to 1.300 DKK/m^2-window exclusive of VAT. Today the additional prize for a B-window compared to a C-window is 150 DKK/m^2-window and for an A-window it is 500 DKK/m^2-window. Glazing without low emission is nearly impossible to find on the market neither as separate glazing or installed in window products. If ordered for special purpose the glazing without low emission will normally cost more than ordinary double glazing with low emission coating and Argon filling. This clearly shows the effect of changing the market focus and competition to products with higher energy efficiency by tightening the regulation.

In the case of boilers prize analysis has shown no relation between efficiency and prize. For boilers the different features e.g. controls, volume, colour and market brand of the producer are more important for the prize than the efficiency and scatters the possible prize picture in relation to efficiency completely.

Adding of cost for the different works included

Prices exclusive of VAT				DKK/m²	DKK/m²
27.16.10,0	Removal of existing insulation	m^2	100	58,09	58,09
Delevery and installation of insulation in wooden construction				DKK/m²	DKK/m²
27.16.95,0	45 mm mineral wool	m^2	100	100,04	100,04
27.16.95,0	70 mm mineral wool	m^2	100	118,54	118,54
27.16.95,0	95 mm mineral wool	m^2	100	131,17	131,17
27.16.95,0	120 mm mineral wool	m^2	100	171,06	171,06
27.16.95,0	145 mm mineral wool	m^2	100	204,86	204,86
27.16.95,0	170 mm mineral wool	m^2	100	238,93	238,93
27.16.95,0	195 mm mineral wool	m^2	100	273,44	273,44
Lining with latches of wooden construction				DKK/m	DKK/m²
47.15.05,0	45 x 45 mm latches on wooden construction	m	110	55,32	60,852
47.15.05,0	45 x 73 mm latches on wooden construction	m	110	62,03	68,233
47.15.05,0	45 x 95 mm latches on wooden construction	m	110	69,94	76,934
Delevery and installation of additional insulation in wooden construction				DKK/m²	DKK/m²
27.16.95,0	45 mm mineral wool	m^2	100	75,04	75,04
27.16.95,0	70 mm mineral wool	m^2	100	93,54	93,54
27.16.95,0	95 mm mineral wool	m^2	100	106,17	106,17
27.16.95,0	120 mm mineral wool	m^2	100	146,06	146,06
27.16.95,0	145 mm mineral wool	m^2	100	179,86	179,86
27.16.95,0	170 mm mineral wool	m^2	100	213,93	213,93
27.16.95,0	195 mm mineral wool	m^2	100	248,44	248,44
Additional insulation of roof construction. Parallel roof. 1960 construction.					
Inclusive of removal of existing insulation and adding of lachches where needed					
mm					DKK/m²
95					189,26
120					229,15
145					262,95
170					297,02
215	Raised construction height and addition of extra insulation layer				432,91
240	Raised construction height and addition of extra insulation layer				458,79
265	Raised construction height and addition of extra insulation layer				480,12
Additional insulation of roof construction. Parallel roof. 1930 construction.					
Inclusive of removal of existing insulation and adding of lachches where needed					
mm					DKK/m²
95					189,26
120					229,15
165	Raised construction height and addition of extra insulation layer				365,04
190	Raised construction height and addition of extra insulation layer				390,92
215	Raised construction height and addition of extra insulation layer				412,25

Relation between size of work and cost level

Delevery and installation of insulation in wooden construction					Faktor:
27.16.95,0	170 mm mineral wool	m^2	50	252,67	1,06
27.16.95,0	170 mm mineral wool	m^2	100	238,93	1,00
27.16.95,0	170 mm mineral wool	m^2	200	226,72	0,95
27.16.95,0	170 mm mineral wool	m^2	400	215,82	0,90
27.16.95,0	170 mm mineral wool	m^2	800	206,06	0,86
27.16.95,0	170 mm mineral wool	m^2	1.600	197,25	0,83
27.16.95,0	170 mm mineral wool	m^2	3.200	189,31	0,79

Requirements to new buildings

The cost optimal calculations in relation to the requirements to new buildings are shown in this chapter. The cost optimal point is identified for each of the reference buildings and for the relevant heat supply systems. The location of the cost optimal point is identified by logical search in the relevant combinations of measures included in the energy saving packages. Future requirement to new buildings is already defined in the Danish Building Regulations. The cost optimality of the needed energy saving packages to comply with the present and the future requirements is also calculated. At the end of the chapter the requirements to the individual elements in the building envelope and to the envelope as such is also analysed.

Single family house

The design of the reference building for new single family house is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

New single family house. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls		Slap	
	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K
0	95	0,346	125	0,248	0	0,329
1	120	0,286	150	0,216	150	0,143
2	145	0,244	190	0,179	200	0,120
3	170	0,213	225	0,156	220	0,113
4	195	0,189	250	0,147	300	0,091
5	220	0,170	300	0,125	350	0,082
6	245	0,154			425	0,070
7	290	0,130				
8	315	0,119				
9	340	0,110				
10	365	0,103				

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Air to water heat pump

The prices available are based on heat pumps tested at 7/35 C. The figures in brackets in the table are for the normal test temperature set of 7/45. In accordance with DS469 an air to water heat pump is required to cover the total heat demand down till an external temperature of -7 C without additional heating from an electric heating element. If connected to a floor heating system with a design supply temperature of 40 C the nominal heating power of the air to water heat pump at test temperatures should be at least 20 % higher than the design heat loss of the building at an external temperature of -12 C inclusive of the heating power needed for heating of domestic hot water. The additional design heating power for production of domestic hot water is estimated to 2,0 kW.

The air to water heat pump has a COP at normal test temperatures of 3,30. The COP used in the calculations is reduced to 3,10 to reflect the de-icing of the external air absorption coil. The heat pump control is on-off. The relative COP at 50 % part load is 0,90.

Water to water heat pump

The situation in the case of water to water heat pumps with pipe in ground is in principle the same as for air to water heat pumps. But due to the more stable temperature in the ground it is sufficient if the nominal heating power of the heat pump at test temperatures is at least as high as the design heat loss of the building inclusive of the heating power needed for heating of domestic hot water when connected to a floor heating system with a design supply temperature of 40 C.

The water to water heat pump has a COP at normal test temperatures of 3,20. The heat pump control is with variable speed. The relative COP at 50 % part load is 1,05.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020.

Natural ventilation

Air exchange rates in the case of natural ventilation are 0,30 l/s per m^2 gross floor area inclusive of infiltration.

Mechanical ventilation

The mechanical ventilation has an mechanical air exchange rate of 0,30 l/s per m^2 gross floor area. The heat recovery efficiency is 0,85 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 0,90 kJ/m^3.

Infiltration

In combination with mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Solar cells, PV

The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 20^o and a horizontal cut off of 5^o. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

New single family house. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations of financial perspective.

Building element		Size, insulation or type	Investment etc. DKK/unit (m²)	Maintenance DKK/unit (m²)	Life time years
District heating unit and connection		All	44.852	1.400	30
Heat pump		6 (4,5) kW	67.075	1.000	25
Air to water		8 (6,0)	71.937		
		10 (7,5)	76.815		
		12 (9,0)	81.678		
Heat pump		4 (3,2) kW	87.644	1.000	25
Water to water		6 (4,8)	95.407		
Incl. pipes in ground		8 (6,4)	105.323		
		10 (8,0)	115.261		
		12 (9,6)	127.768		
Loft		95 mm	126	0	40
		120	161		
		145	191		
		170	220		
		195	250		
		220	264		
		245	306		
		290	386		
		315	411		
		340	423		
		365	459		
Wall		125 mm	2.344	0	60
		150	2.366		
		190	2.408		
		225	2.460		
		250	2.538		
		300	2.581		
Slap		0 mm	450	0	60
		150	674		
		200	734		
		220	757		
		300	890		
		350	985		
		425	1.095		
Foundations		125 mm	1.298	0	60
		150	1.355		
		190	1.544		
		225	1.733		
		250	1.825		
		300	2.084		
Windows		C	3.235	0	40
		B	3.349		
		A	3.644		
Ventilation		Natural	54	0	50
Ventilation		Mechanical	88.826	1.000	25
PV	1:	1,14 kWp	32.930	0,5 % p.a.	20
	2:	2,28	62.880		
	3:	3,42	89.852		
	4:	4,56	113.844		
	5:	5,70	134.858		

The table below list the packages of energy saving measures calculated for the new single family house with district heating. Each package includes insulation on the loft, insulation in the external walls, insulation in the ground slap, windows with specified energy class, natural or mechanical ventilation and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the single family house with district heating the energy frame requirement in the Danish Building Regulations 2010, BR10 is tighter than the point of cost optimality, showing a gap of -15,7 %. For the Low Energy Buildings 2015 the over-performance increases to a gap - 44,9 %. For Buildings 2020 the over-performance increases further to a gap of - 57,0 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

In the table on top of next page the same is shown for the new single family in the case of heating with a ground coupled heat pump.

For the single family house with heating from a heat pump the cost optimum point is at a lower primary energy demand and the energy frame requirement in the Danish Building Regulations 2010, BR10 is close to the point of cost optimality, showing a gap of only -2,8 %. For the Low Energy Buildings 2015 this increases to an over-performance with a gap of - 49,8 %. For Buildings 2020 the over-performance increases further to a gap of - 58,0 %.

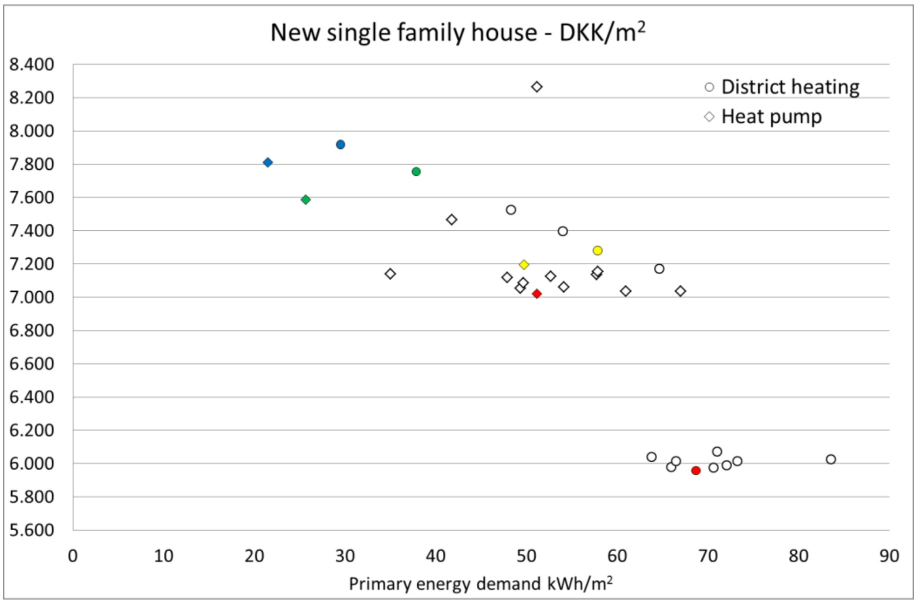
New single family house with district heating. Energy measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap	Windows	Ventilation	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m^2	DKK/m^2	DKK/m^2
SF.DH.401.B.NV.No	195	125	150	B	NV	No	72,08	4.116	5.989
SF.DH.500.B.NV.No	220	125	0	B	NV	No	83,54	4.047	6.027
SF.DH.501.B.NV.No	220	125	150	B	NV	No	70,58	4.119	5.977
SF.DH.511.C.NV.No	220	150	150	C	NV	No	73,22	4.126	6.014
SF.DH.511.B.NV.No	220	150	150	B	NV	No	68,66	4.120	5.958
SF.DH.511.A.NV.No	220	150	150	A	NV	No	65,98	4.162	5.981
SF.DH.511.B.MV.No	220	150	150	B	MV	No	64,61	4,873	7.171
SF.DH.511.B.MV.PV1	220	150	150	B	MV	PV1	53,99	5,134	7.397
SF.DH.521.C.NV.No	220	190	150	C	NV	No	71,01	4.191	6.072
SF.DH.521.B.NV.No	220	190	150	B	NV	No	66,45	4.185	6.015
SF.DH.521.A.NV.No	220	190	150	A	NV	No	63,81	4.227	6.039
SF.DH.721.B.MV.No	290	190	220	B	MV	No	57,85	5.020	7.281
SF.DH.944.B.MV.No	340	250	300	B	MV	No	48,30	5.298	7.525
SF.DH.944.B.MV.PV1	340	250	300	B	MV	PV1	37,85	5.558	7.755
SF.DH.1055.A.MV.PV1	365	300	350	A	MV	PV1	29,49	5.762	7.918

New single family house with heat pump. Energy measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap	Windows	Ventilation	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SF.HPG.401.B.NV.No	195	125	150	B	NV	No	57,73	4.749	7.136
SF.HPG.500.B.NV.No	220	125	0	B	NV	No	60,94	4.628	7.034
SF.HPG.501.B.NV.No	220	125	150	B	NV	No	57,85	4.762	7.155
SF.HPG.511.C.NV.No	220	150	150	C	NV	No	54,16	4.732	7.060
SF.HPG.511.B.NV.No	220	150	150	B	NV	No	51,14	4.737	7.021
SF.HPG.511.A.NV.No	220	150	150	A	NV	No	49,34	4.785	7.053
SF.HPA.511.B.NV.No	220	150	150	B	NV	No	66,98	4.599	7.037
SF.HPG.511.B.NV.PV1	220	150	150	B	NV	PV1	35,05	4.966	7.140
SF.HPG.511.B.MV.No	220	150	150	B	MV	No	51,17	5,520	8.264
SF.HPG.521.C.NV.No	220	190	150	C	NV	No	52,69	4.802	7.126
SF.HPG.521.B.NV.No	220	190	150	B	NV	No	49,67	4.808	7.086
SF.HPG.521.A.NV.No	220	190	150	A	NV	No	47,88	4.856	7.119
SF.HPG.721.C.NV.No	290	190	150	C	NV	No	49,72	4.895	7.196
SF.HPG.944.B.NV.No	340	250	300	B	NV	No	41,75	5.209	7.467
SF.HPG.944.B.NV.PV1	340	250	300	B	NV	PV1	25,66	5.438	7.587
SF.HPG.1055.A.NV.PV1	365	300	350	A	NV	PV1	21,49	5.669	7.811

Finally the relation between primary energy demand and financial net present value is plotted for the two heating supplies: district heating and heat pump. The jump in net present value for the new single family house with district heating relates to installation of mechanical ventilation. Mechanical ventilation will also possibly improve the indoor climate. The installation of mechanical ventilation can thus not be evaluated only based on the cost optimality in relation to energy consumption.



New single family house with district heating or heat pump. Primary energy consumption and financial net present value. Red point is cost optimal. Yellow point is BR10 requirement. Green point is Low Energy Building 2015. Blue point is Building 2020.

Multifamily house

The design of the reference building for new multifamily house is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

New multifamily house. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls		Slap		Basement wall		Basement slap	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	95	0,346	125	0,285	0	0,329	0	2,985	0	0,634
1	120	0,286	150	0,235	150	0,143	45	0,685	50	0,346
2	145	0,244	190	0,203	200	0,120	70	0,480	75	0,282
3	170	0,213	225	0,190	220	0,113	95	0,369	100	0,238
4	195	0,189	250	0,164	300	0,091				
5	220	0,170	300	0,142	350	0,082				
6	245	0,154			425	0,070				
7	290	0,130								
8	315	0,119								
9	340	0,110								
10	365	0,103								

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020. The cost for windows is 10 % lower compared to small buildings.

Standard mechanical ventilation

The mechanical ventilation is constant 35 l/s per flat. The heat recovery efficiency is 0,70 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,80 kJ/m^3.

Improved mechanical ventilation

The mechanical ventilation has an mechanical air exchange rate of 0,30 l/s per m^2 gross floor area in average due to demand control. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,50 kJ/m^3.

Infiltration

In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Solar cells, PV

The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 30^o and a horizontal cut off of 5^o. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

New multifamily house. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations of financial perspective.

Building element		Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance etc. DKK/unit (m^2)	Life time years
District heating installation and connection		All	81.271	1.500 + 150/kW	30
Loft		95 mm	119	0	40
		120	152		
		145	180		
		170	207		
		195	235		
		220	249		
		245	288		
		290	364		
		315	387		
		340	399		
		365	432		
Wall		125 mm	2.758	0	60
		150	2.778		
		190	2.811		
		225	2.859		
		250	2.931		
		300	2.991		
Slap		0 mm	450	0	60
		150	674		
		200	734		
		220	757		
		300	890		
		350	985		
		425	1.095		
Basement wall		0 mm	0	0	60
		45	433		
		70	460		
		95	508		
Basement slap		0 mm	0	0	60
		50	275		
		75	321		
		100	368		
Windows		C	2.912	0	40
		B	3.014		
		A	3.280		
Mechanical ventilation		Standard	575	5	25
		Improved	700		
PV	1:	1,14 kWp	32.930	0,5 % p.a.	20
	2:	2,28	62.880		
	3:	3,42	89.852		
	4:	4,56	113.844		
	5:	5,70	134.858		

The table below list the packages of energy saving measures calculated for the new multifamily house with district heating. Each package includes insulation on the loft, insulation in the external walls, insulation in the ground slap in the stairway, insulation of the basement partition wall to the stairway, insulation of the basement slap, windows with specified energy class, standard or improved mechanical ventilation and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the multifamily house with district heating the energy frame requirement in the Danish Building Regulations 2010, BR10 is a little tighter than the point of cost optimality, showing a gap of -9,2 %. For the Low Energy Buildings 2015 the over-performance increases to a gap - 36,1 %. For Buildings 2020 the over-performance increases further to a gap of - 44,7 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

New multifamily house with district heating. Energy measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap	B.w.	B.s.	Window	Vent.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
MF.DH.41120.C.S.No	195	150	150	70	0	C	St.	No	74,16	3.229	5.189
MF.DH.50120.C.S.No	220	125	150	70	0	C	St.	No	75,70	3.235	5.213
MF.DH.51100.C.S.No	220	150	150	0	0	C	St.	No	76,14	3.227	5.210
MF.DH.51110.C.S.No	220	150	150	45	0	C	St.	No	73,96	3.231	5.189
MF.DH.51120.C.S.No	220	150	150	70	0	C	St.	No	73,67	3.228	5.181
MF.DH.51121.C.S.No	220	150	150	70	50	C	St.	No	71,57	3.275	5.216
MF.DH.51130.C.S.No	220	150	150	95	0	C	St.	No	73,51	3.229	5.182
MF.DH.52120.C.S.No	220	190	150	70	0	C	St.	No	72,39	3.233	5.174
MF.DH.52120.C.I.No	220	190	150	70	0	C	Imp.	No	58,37	3.316	5.141
MF.DH.52120.B.I.No	220	190	150	70	0	B	Imp.	No	53,61	3.301	5.070
MF.DH.52120.A.I.No	220	190	150	70	0	A	Imp.	No	50,72	3.333	5.078
MF.DH.52120.C.I.PV4	220	190	150	70	0	C	Imp.	PV4	49,05	3.416	5.148
MF.DH.52120.B.I.PV4	220	190	150	70	0	B	Imp.	PV4	44,30	3.402	5.077
MF.DH.52120.A.I.PV4	220	190	150	70	0	A	Imp.	PV4	41,41	3.434	5.085
MF.DH.52120.C.I.PV5	220	190	150	70	0	C	Imp.	PV5	47,92	3.438	5.163
MF.DH.61120.C.S.No	245	150	150	70	0	C	St.	No	73,67	3.239	5.195
MF.DH.52131.B.I.PV4	220	190	150	95	50	B	Imp.	PV4	42,05	3.448	5.109
MF.DH.52131.A.I.PV4	220	190	150	95	50	A	Imp.	PV4	39,26	3.487	5.128
MF.DH.41131.B.I.PV2	195	150	150	95	50	B	Imp.	PV2	48,39	3.398	5.126
MF.DH.72131.A.I.PV5	290	190	150	95	50	A	Imp.	PV5	34,25	3.519	5.114
MF.DH.105333.A.I.PV5	365	300	220	95	100	A	Imp.	PV5	29,66	3.596	5.157

Office building

The design of the reference building for office buildings is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

New office building. Insulation thickness in the building elements and the related U-value of the construction.

Level	Flat roof		Walls, heavy		Walls, light		Basement slap	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	100	0,341	125	0,285	190	0,213	0	1,778
1	180	0,196	150	0,235	215	0,190	50	0,532
2	230	0,155	190	0,203	240	0,171	75	0,394
3	280	0,128	225	0,190	290	0,143	100	0,313
4	340	0,106	250	0,164	335	0,125		
5	440	0,082	300	0,142	360	0,117		
6	540	0,067			385	0,109		

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020. The cost for windows is 10 % lower compared to small buildings.

Standard mechanical ventilation

The mechanical ventilation is constant 1,80 l/s per m^2 gross floor area. The heat recovery efficiency is 0,70 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,80 kJ/m^3.

Improved mechanical ventilation

The mechanical ventilation has an average air exchange rate of 0,90 l/s per m^2 gross floor area due to demand control. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,20 kJ/m^3.

Infiltration

In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,80 l/s per m^2 gross floor area in average. In relation to the improved ventilation the air exchange rate in average is up till 2,40 l/s per m^2 gross floor area and includes also airing at night.

Solar cells, PV

The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, Rp of 0,75. The cells are mounted on the roof in a rack with a slope of 45^o and a horizontal cut off of 15^o due to the need of having the racks in more rows. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

Standard lighting system

Installed power in the office areas is 8 W/m^2. There are automatic daylight control on-off in 2 zones from the façade and one zone in the middle..

Improved lighting system

Installed power in office areas is 6 W/m^2. There is daylight dimming control and present sensors in 2 zones from the façade and one zone in the middle.

New office building. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT.

Building element		Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance etc. DKK/unit (m^2)	Life time years
District heating installation and connection		All	108.449	1.500 + 150/kW	30
Flat roof		100 mm	395	0	40
		180	510		
		230	599		
		280	680		
		340	793		
		440	934		
		540	1.092		
Walls, heavy		125 mm	2.758	0	60
		150	2.778		
		190	2.811		
		225	2.859		
		250	2.931		
		300	2.991		
Walls, light		190 mm	1.795	0	60
		215	1.880		
		240	1.934		
		290	2.052		
		335	2.222		
		360	2.243		
		385	2.286		
Basement slap		0 mm	0	0	60
		50	275		
		75	321		
		100	368		
Windows		C	2.912	0	40
		B	3.014		
		A	3.280		
Mechanical ventilation		Standard	955	5	25
		Improved	1.250		
Lighting		Standard	213	0	25
		Improved	320		
PV	1:	5,70 kWp	134.858	0,5 % p.a.	20
	X::	5,70 x X	134.858 x X		

The table below list the packages of energy saving measures calculated for the new office building with district heating. Each package includes insulation on the roof, insulation in the external heavy walls, insulation in the light external walls, insulation of the basement slap, windows with specified energy class, standard or improved mechanical ventilation, standard or improved lighting system and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the office building with district heating the energy frame requirement in the Danish Building Regulations 2010, BR10 shows a gap of 31,2 % to the point of cost optimal. For the Low Energy Buildings 2015 the result shifts to an over-performance with a gap of - 16,0 %. For Buildings 2020 the over-performance increases to a gap of - 37,3 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

The relatively high energy consumption in the BR10 office building mainly relates to the electricity used for lighting.

PV are not cost efficient, but are very close to be cost efficient.

New office building with district heating. Energy measures, primary energy consumption, macro economical and financial net present value.

Code	Roof	W.h.	W.l	Slap.	Win.	Vent.	Light	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
OB.DH.1213.B.S.S.No	180	190	215	100	B	St.	St.	No	103,02	2.768	3.545
OB.DH.1213.B.I.S.No	180	190	215	100	B	Imp.	St.	No	75,22	2.844	3.489
OB.DH.1213.B.I.I.No	180	190	215	100	B	Imp.	Imp.	No	51,44	2.844	3.292
OB.DH.1213.C.I.I.No	180	190	215	100	C	Imp.	Imp.	No	57,00	2.850	3.329
OB.DH.1213.A.I.I.No	180	190	215	100	A	Imp.	Imp.	No	48,12	2.881	3.310
OB.DH.1213.B.I.I.PV5	180	190	215	100	B	Imp.	Imp.	PV5	33,12	2.992	3.296
OB.DH.1213.B.I.I.PV7	180	190	215	100	B	Imp.	Imp.	PV7	25,79	3.051	3.297
OB.DH.1213.B.I.I.PV8	180	190	215	100	B	Imp.	Imp.	PV8	25,15	3.093	3.335
OB.DH.0213.B.I.I.No	100	190	215	100	B	Imp.	Imp.	No	53,96	2.836	3.297
OB.DH.1103.B.I.I.No	180	150	190	100	B	Imp.	Imp.	No	52,07	2.835	3.287
OB.DH.1113.B.I.I.No	180	150	215	100	B	Imp.	Imp.	No	51,78	2.843	3.293
OB.DH.1203.B.I.I.No	180	190	190	100	B	Imp.	Imp.	No	51,74	2.836	3.286
OB.DH.1212.B.I.I.No	180	190	215	75	B	Imp.	Imp.	No	52,41	2.840	3.294
OB.DH.2213.B.I.I.No	230	190	215	100	B	Imp.	Imp.	No	50,80	2.855	3.299
OB.DH.1213.B.I.S.PV2	180	190	215	100	B	Imp.	St.	PV2	67,89	2.904	3.490
OB.DH.2213.B.I.I.PV2	230	190	215	100	B	Imp.	Imp.	PV2	43,48	2.914	3.301
OB.DH.3223.A.I.I.PV4	280	190	240	100	A	Imp.	Imp.	PV4	32,45	3.027	3.335

Sensitivity analysis

Sensitivity analysis are performed with a higher energy price development of + 2,0 % p.a. and with a higher discount rate and interest rate of +2,0 % p.a. The analysis is performed for the new single family house with district heating and for the new office building with district heating, see table at this page and on next page.

No change of the location of the cost optimal point can be observed from the sensitivity analysis in relation to the improvement of building envelope and installations. The difference between energy efficient solutions and less energy efficient solutions are also nearly the same both with increased energy price and with increased discount and investment rates.

The real difference is in relation to PV, where PV is cost efficient in the office building if the energy price develops with + 2,0 % p.a. This will also significantly move the point of cost optimal to a lower primary energy demand.

New single family house with district heating. Energy measures, primary energy consumption, macro economical and financial net present value. Sensitivity analyses.

		Energy + 2,0 % p.a.		Rates + 2,0 % p.a.	
Code	Energy	NPV-m	NPV-f	NPV-m	NPV-f
	kWh/m²	DKK/m²	DKK/m²	DKK/m²	DKK/m²
SF.DH.401.B.NV.No	72,08	4.332	6.600	4.272	5.964
SF.DH.500.B.NV.No	83,54	4.287	6.716	4.171	5.930
SF.DH.501.B.NV.No	70,58	4.432	6.578	4.278	5.959
SF.DH.511.C.NV.No	73,22	4.345	6.633	4.282	5.985
SF.DH.511.B.NV.No	68,66	4.330	6.545	4.283	5.951
SF.DH.511.A.NV.No	65,98	4.366	6.550	4.332	5.989
SF.DH.511.B.MV.No	64,61	5,124	7.833	4,983	6.994
SF.DH.511.B.MV.PV1	53,99	5,372	7.977	5,232	7.224
SF.DH.521.C.NV.No	71,01	4.405	6.676	4.359	6.064
SF.DH.521.B.NV.No	66,45	4.390	6.588	4.361	6.030
SF.DH.521.A.NV.No	63,81	4.427	6.594	4.409	6.069
SF.DH.721.B.MV.No	57,85	5.257	7.897	5.154	7.153
SF.DH.944.B.MV.No	48,30	5.515	8.076	5.481	7.485
SF.DH.944.B.MV.PV1	37,85	5.765	8.226	5.731	7.718
SF.DH.1055.A.MV.PV1	29,49	5.950	8.332	5.968	7.948

New office building with district heating. Energy measures, primary energy consumption, macro economical and financial net present value. Sensitivity analysis.

		Energy + 2,0 % p.a.		Rates + 2,0 % p.a.	
Code	Energy	NPV-m	NPV-f	NPV-m	NPV-f
	kWh/m^2	DKK/m^2	DKK/m^2	DKK/m^2	DKK/m^2
OB.DH.1213.B.S.S.No	103,02	2.900	3.872	2.892	3.526
OB.DH.1213.B.I.S.No	75,22	2.946	3.732	3.002	3.543
OB.DH.1213.B.I.I.No	*51,44*	2.924	3.667	3.021	3.402
OB.DH.1213.C.I.I.No	57,00	2.935	3.517	3.020	3.427
OB.DH.1213.A.I.I.No	48,12	2.957	3.477	3.067	3.433
OB.DH.1213.B.I.I.PV5	*33,12*	3.060	3.423	3.179	3.442
OB.DH.1213.B.I.I.PV7	*25,79*	3.114	3.405	3.242	3.458
OB.DH.1213.B.I.I.PV8	25,15	3.156	3.441	3.283	3.496
OB.DH.0213.B.I.I.No	53,96	2.919	3.477	3.009	3.401
OB.DH.1103.B.I.I.No	52,07	2.916	3.463	3.009	*3.393*
OB.DH.1113.B.I.I.No	51,78	2.924	3.469	3.019	3.402
OB.DH.1203.B.I.I.No	51,74	2.917	3.461	3.011	3.393
OB.DH.1212.B.I.I.No	52,41	2.921	3.470	3.015	3.401
OB.DH.2213.B.I.I.No	50,80	2.934	3.472	3.035	3.413
OB.DH.1213.B.I.S.PV2	67,89	3.000	3.715	3.065	3.559
OB.DH.2213.B.I.I.PV2	43,48	2.989	3.454	3.098	3.428
OB.DH.3223.B.I.I.PV4	32,45	3.092	3.460	3.226	3.393

Requirements to the building envelope elements

In this section the component requirements to the individual elements in the building envelope and to the building envelope as such is analysed. The two requirement types are only used as additional requirements to the energy frame requirement analysed in the previous sections. The method and data used is in principles the same as for the analyses on building level. The heating demand calculation is simplified by using the heating degree day method with 3600 DD/ann.

Individual building envelope elements

The cost optimal level of insulation in the building envelope elements and the requirements in BR10 to the same elements is shown in the tables below. The first table is for single family houses and the second table is for larger buildings e.g. multifamily houses and office buildings. The only difference in the two situations is the lower cost for the constructions in larger buildings.

The component requirements in them self has a significant gap to cost optimality. It shows a wide flexibility for the designer of a new building to use the solution for the component in envelope he prefers. The resulting energy efficiency of the building is any how regulated by the energy frame requirement. There is no real difference between small and large buildings. The results are also nearly the same in case of heat pump heating.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to constructions in the building envelope of new buildings. Single family houses with district heating.

	EU: mm insul.	U-value $W/m^2 K$	DK: mm insul.	U-value $W/m^2 K$	Gap %
Loft	220	0,170	195	0,200	17,6
Parallel roof *	220	0,170	195	0,200	17,6
Flat roof *	180	0,196	180	0,200	2,0
Heavy wall	150	0,216	125	0,300	38,9
Light wall *	190	0,213	145	0,300	40,8
Slap on ground, floor heating	150	0,143	100	0,200	39,9

* Not in the reference buildings.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to constructions in the building envelope of new buildings. Large buildings with district heating.

	EU: mm insul.	U-value $W/m^2 K$	DK: mm insul.	U-value $W/m^2 K$	Gap %
Loft	220	0,170	195	0,200	17,6
Parallel roof *	220	0,170	195	0,200	17,6
Flat roof	180	0,196	180	0,200	2,0
Heavy wall	190	0,203	125	0,300	47,8
Light wall	190	0,213	145	0,300	40,8
Basement slap	100	0,313	75	0,400	27,8
Basement slap, floor heating	50+0	0,634	50+50	0,400	- 36,9

* Not in the reference buildings.

Building envelope exclusive of windows and doors

The cost optimality of the requirements to the design heat loss of the building envelope exclusive of windows and doors is analysed in the same way as the requirements to the individual elements in the building envelope. The result for the different buildings of course depends on the specific choice of solutions. In the tables below and on next page the cost optimality is analysed for the solutions used in the three reference building to comply with the BR10, Low Energy Building 2015 and Building 2020 requirement to the design heat loss of the building envelope exclusive of windows and doors.

In the single family house reference building the constructions used to comply with the requirement to the heat loss of the building envelope in BR10 is cost optimal or beyond cost optimal with a gap up till - 24 %. For the Low Energy Buildings 2015 the over-performance results in gap of - 32 % to - 36 %. For Buildings 2020 the over-performance increases to a gap of - 39 % to - 43 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

In the multifamily house reference building the result is more mixed in relation to the cost optimality of the constructions used to comply with the requirement to the heat loss of the building envelope in BR10. The result varies from a gap of 16 % to a gap of - 45 %. For the Low Energy Buildings 2015 the result is just cost optimal or beyond cost optimal with a gap up till - 45 %. For Buildings 2020 there is an over-performance increase with a gap of - 39 % to - 62 %. The results for the multifamily house indeed show the flexibility for the designer to use the solutions he likes.

In the office reference building the constructions used to comply with the requirement to the heat loss of the building envelope in BR10 is cost optimal or beyond cost optimal with a gap up till - 11 %. For the Low Energy Buildings 2015 the gap is 0 % to - 36 %. For Buildings 2020 the gap is 0 % to - 35 %. Also in the office building there is significant flexibility to the designer.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to constructions in the building envelope of new buildings. Values needed to comply with the general requirement to heat loss from the building envelope exclusive of windows and doors. Single family house with district heating.

	EU: mm insul.	U-value $W/m^2 K$	DK: mm insul.	U-value $W/m^2 K$	Gap %
BR10					
Loft	220	0,170	290	0,130	- 23,5
Heavy wall	150	0,216	190	0,179	- 17,1
Slap on ground, floor heating	150	0,143	150	0,143	0
Low energy building 2015					
Loft	220	0,170	340	0,110	- 35,3
Heavy wall	150	0,216	250	0,147	- 31,9
Slap on ground, floor heating	150	0,143	300	0,091	- 36,4
Building 2020					
Loft	220	0,170	365	0,103	- 39,4
Heavy wall	150	0,216	300	0,125	- 42,1
Slap on ground, floor heating	150	0,143	350	0,082	- 42,7

EU cost-optimal level and Danish energy requirement level in BR10 in relation to constructions in the building envelope of new buildings. Values needed to comply with the general requirement to heat loss from the building envelope exclusive of windows and doors. Multifamily house with district heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
<u>BR10</u>					
Loft	220	0,170	195	0,189	11,2
Heavy wall	190	0,203	150	0,235	15,8
Basement slap	50+0	0,634	50+50	0,346	- 45,4
<u>Low energy building 2015</u>					
Loft	220	0,170	290	0,130	- 23,5
Heavy wall	190	0,203	190	0,203	0
Basement slap	50+0	0,634	50+50	0,346	- 45,4
<u>Building 2020</u>					
Loft	220	0,170	365	0,103	- 39,4
Heavy wall	190	0,203	300	0,142	- 30,0
Basement slap	50+0	0,634	50+100	0,238	- 62,4s

EU cost-optimal level and Danish energy requirement level in BR10 in relation to constructions in the building envelope of new buildings. Values needed to comply with the general requirement to heat loss from the building envelope exclusive of windows and doors. Office building with district heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
<u>BR10</u>					
Flat roof	180	0,196	180	0,196	0
Heavy wall	190	0,203	190	0,203	0
Light wall	190	0,213	215	0,190	- 10,8
Basement slap	100	0,313	100	0,313	0
<u>Low energy building 2015</u>					
Flat roof	180	0,196	230	0,155	- 20,9
Heavy wall	190	0,203	190	0,203	0
Light wall	190	0,213	215	0,190	- 10,8
Basement slap	100	0,313	100	0,313	0
<u>Building 2020</u>					
Flat roof	180	0,196	280	0,128	- 34,7
Heavy wall	190	0,203	190	0,203	0
Light wall	190	0,213	240	0,171	- 19,7
Basement slap	100	0,313	100	0,313	0

Renovation of existing buildings

The cost optimal calculations in relation to the requirements to existing buildings in case of major renovation or equivalent are shown in this chapter. The cost optimal point is identified for each of the reference buildings and for the relevant heat supply systems. The location of the cost optimal point is identified by logical search in the relevant combinations of measures included in the energy saving packages. The cost optimality of the needed energy saving packages to comply with the present requirements to existing building is also calculated. In addition the cost optimality of the tightening of the requirements to windows in existing building in 2015 and 2020 is calculated.

In the first section of the chapter the requirements to the individual elements in the building envelope of existing buildings is analysed. These requirements are applied both in the case of major renovations but also in the case of minor renovations.

Component requirements

In this section the component requirements to the individual elements in the building envelope of existing buildings undergoing renovation is analysed based on financial costs. The method and data used is in principles the same as for the analyses on building level. The heating demand calculation is simplified by using the heating degree day method with 3600 DD/ann.

The cost optimal level of insulation in the building envelope elements and the requirements in BR10 to the same elements is shown in the tables below. The first table is for single family houses with district heating. The second table is for single family houses with natural gas heating. The last table is for larger buildings with district heating e.g. multifamily houses and office buildings. The only difference in the two situations is the lower cost for the constructions in larger buildings.

In relation to U-values negative difference indicates the requirements to be tighter than the EU cost-optimal level.

For the parallel roof both the EU cost optimum insulation thickness and the Danish requirement based on profitability is to fill the available construction height.

Filling of cavity walls with insulations is included both in relation to the EU cost optimum insulation thickness and in relation to the Danish requirement based on profitability. The same is the case with filling of cavity in wooden construction basement slaps over unheated basements.

The result for buildings heated with heat pumps are between the results for building heated by district heating and buildings heated by natural gas. If the heat pump is new and efficient the results for buildings with heat pumps are close to the results for district heated buildings. If the heat pump is old and low efficient the result are close to the results for buildings with natural gas heating

The requirements in the Danish Building Regulations to the individual building element in the building envelope in case of renovation inclusive of major renovations are in general at the point of cost optimal or tighter with a gap of -15 % to - 40 %. This probably has to do with the profitability provision in the Building Regulations. The only exceptions are insulation of lofts in small building where there is a gap to the point of cost optimal of 19 % and insulation of concrete basement slap in larger buildings where there is a gap of 28 %. The two gaps relates to the basic U-value requirements not being tight enough.

There are no really different between small and large building. The main different has to do with the type of heat supply and especially the costs related to the energy consumption.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to renovation of the constructions in the building envelope. Single family houses with district heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
Loft, newer	170	0,213	240	0,150	- 29,6
Loft, older	215	0,178	240	0,150	- 15,7
Parallel roof *	170	0,213	170	0,213	0
Flat roof *	100	0,341	100	0,341	0
Heavy solid wall, external insulation	50	0,536	50	0,536	0
Heavy insul. cavity wall, ext. insulation	0	0,439	0	0,439	0
Insulated light wall, additional insulation	95	0,244	140	0,200	- 18,0
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	50	0,353	50	0,353	0

* Not in the reference buildings.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to renovation of the constructions in the building envelope. Single family houses with natural gas heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
Loft, newer	290	0,126	240	0,150	19,0
Loft, older	215	0,178	265	0,150	- 15,7
Parallel roof *	170	0,213	265	0,150	- 29,6
Flat roof *	180	0,196	230	0,155	- 20,9
Heavy solid wall, external insulation	100	0,321	200	0,200	- 37,7
Heavy insul. cavity wall, ext. insulation	0	0,439	0	0,439	0
Insulated light wall, additional insulation	95	0,244	140	0,200	- 18,0
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	100	0,241	200	0,148	- 38,6

* Not in the reference buildings.

EU cost-optimal level and Danish energy requirement level in BR10 in relation to renovation of the constructions in the building envelope. Large buildings with district heating.

	EU: mm insul.	U-value W/m^2 K	DK: mm insul.	U-value W/m^2 K	Gap %
Loft, newer	195	0,189	240	0,150	- 20,6
Loft, older	215	0,178	265	0,150	- 15,7
Parallel roof *	170	0,213	265	0,150	- 29,6
Flat roof	100	0,341	100	0,341	0
Heavy solid wall, external insulation	50	0,536	100	0,321	- 40,1
Heavy insul. cavity wall, ext. insulation	0	0,439	0	0,439	0
Insulated light wall, additional insulation	95	0,244	95	0,244	0
Basement slap, concrete, addit. insulation	100	0,313	75	0,400	27,8
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	50	0,353	100	0,241	- 31,7

* Not in the reference buildings.

Single family house 1930

The design and basic starting data of the reference building for existing single family house from 1930 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

Single family house 1930. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls, cavity		Walls, external		Floor slap	
	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K	Mm	W/m^2 K
0	95	0,394	0	1,668			0	0,960
1	120	0,329	70	0,640			70	0,485
2	145	0,282			+ 50	0,305		
3	170	0,235			+100	0,240		
4	190	0,203			+200	0,176		
5	215	0,178						
6	240	0,159						
7	265	0,144						
8	290	0,131						
9	315	0,120						
10	335	0,113						

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

New gas boiler

The new condensing gas boiler has an efficiency of 0,97 at full load and 1,06 at part load. The new boiler also includes new, well insulated DHW tank and new efficient control of the heating.

New air to water heat pump

The prices available are based on heat pumps tested at 7/35 C. The figures in brackets in the table are for the normal test temperature set of 7/45. In accordance with DS469 an air to water heat pump is required to cover the total heat demand down till an external temperature of -7 C without additional heating from an electric heating element. If connected to a floor heating system with a design supply temperature of 40 C the nominal heating power of the air to water heat pump at test temperatures should be at least 20 % higher than the design heat loss of the building at an external temperature of -12 C inclusive of the heating power needed for heating of domestic hot water. The additional design heating power for production of domestic hot water is estimated to 2,0 kW.

The air to water heat pump has a COP at normal test temperatures of 3,30. The COP used in the calculations is reduced to 3,10 to reflect the de-icing of the external air absorption coil. The heat pump control is on-off. The relative COP at 50 % part load is 0,90.

Loft

Prices are inclusive of removal of existing insulation. This is more cost efficient than relining of partly damaged, existing insulation.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020.

Natural ventilation

Air exchange rates in the case of natural ventilation are 0,45 l/s per m^2 gross floor area inclusive of infiltration.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Existing single family house 1930. Investment in the energy saving measures, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations of financial perspective.

Building element	Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance DKK/unit (m^2)	Life time years
District heating unit	All	27.621	1.400	30
Gas boiler	16 kW	34.245	2.000	30
Heat pump	8 (6,0)	75.349	1.000	25
Air to water	10 (7,5)	80.227		
	12 (9,0)	85.089		
Loft	95 mm	206	0	40
	120	245		
	145	278		
	170	319		
	190	338		
	215	350		
	240	414		
	265	448		
	290	481		
	315	516		
	335	587		
Wall, cavity	0 mm	0	0	60
And then external	70	225		
	120	1.648		
	170	2.005		
	270	2.679		
Slap over basement	0 mm	0	0	60
	70	179		
Windows	C	3.718	0	40
	B	3.838		
	A	4.179		

The tables below and on next page list the packages of energy saving measures calculated for the existing single family house from 1930. Each package includes additional insulation on the loft, additional insulation on the external walls, additional insulation in the basement slap, windows with specified energy class and new district heating unit alternatively new condensing gas or new air to water heat pump. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

Solar heating, mechanical ventilation and PV are not tested as measures in the single house from 1930, because it is known from the analysis of the existing single house from 1960, that they are not cost efficient.

For the single family house from 1930 with district heating, gas boiler or heat pump the requirement in the Danish Building Regulations 2010, BR10 is nearly exact at the point of cost optimality, showing a gap of 0,3 -1,8 %. When the regulations in 2015 will include an requirement to use energy class B windows there is with to day's prices a small over-performance compared to the point of cost optimal with a gap of -0,6 to - 2,0 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased a little to - 2,0 % to -3,3 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

Existing single family house from 1930 with district heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
S30.DH.000.T.N.O.No	0	0	0	Th.	NV	Org.	No	315,92	2.251	6.364
S30.DH.000.B.N.O.No	95	0	0	B	NV	Org.	No	298,26	2.896	6.983
S30.DH.300.B.N.O.No	170	0	0	B	NV	Org.	No	284,44	2.911	6.854
S30.DH.310.B.N.O.No	170	70	0	B	NV	Org.	No	205,20	2.579	5.585
S30.DH.320.B.N.O.No	170	120	0	B	NV	Org.	No	179,45	3.417	6.356
S30.DH.311.B.N.O.No	170	70	70	B	NV	Org.	No	189,07	2.620	5.470
S30.DH.411.B.N.O.No	190	70	70	B	NV	Org.	No	186,30	2.620	5.440
S30.DH.511.B.N.O.No	215	70	70	B	NV	Org.	No	184,14	2.618	5.414
S30.DH.611.B.N.O.No	240	70	70	B	NV	Org.	No	182,50	2.665	5.455
S30.DH.511.A.N.O.No	215	70	70	A	NV	Org.	No	182,07	2.655	5.438
S30.DH.511.B.N.N.No	215	70	70	B	NV	New	No	153,61	2.702	5.126
S30.DH.711.C.N.N.No	215	70	70	C	NV	New	No	154,13	2.776	5.223
S30.DH.711.B.N.N.No	215	70	70	B	NV	New	No	150,67	2.772	5.182
S30.DH.711.A.N.N.No	215	70	70	A	NV	New	No	148,60	2.810	5.207

Existing single family house from 1930 with natural gas heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
S30.Gas.000.T.N.O.No	0	0	0	Th.	NV	Org.	No	440,71	2.781	9.797
S30.Gas.511.B.N.O.No	215	70	70	B	NV	Org.	No	240,80	2.899	7.145
S30.Gas.521.B.N.O.No	215	120	70	B	NV	Org.	No	204,57	3.704	7.645
S30.Gas.611.B.N.O.No	240	70	70	B	NV	Org.	No	238,42	2.944	7.168
S30.Gas.511.A.N.O.No	215	70	70	A	NV	Org.	No	237,87	2.934	7.148
S30.Gas.511.B.N.N.No	215	70	70	B	NV	New	No	181,57	3.014	6.433
S30.Gas.711.C.N.N.No	215	70	70	C	NV	New	No	182,21	3.088	6.534
S30.Gas.711.B.N.N.No	215	70	70	B	NV	New	No	177,89	3.083	6.467
S30.Gas.711.A.N.N.No	215	70	70	A	NV	New	No	175,39	3.120	6.478

Existing single family house from 1930 with heat pump air - water heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
S30.HPA.000.T.N.O.No	0	0	0	Th.	NV	Org.	No	456,63	2.858	10.778
S30.HPA.411.B.N.O.No	190	70	70	B	NV	Org.	No	232,83	2.706	7.008
S30.HPA.511.B.N.O.No	215	70	70	B	NV	Org.	No	229,51	2.698	6.947
S30.HPA.611.B.N.O.No	240	70	70	B	NV	Org.	No	226,98	2.741	6.962
S30.HPA.521.B.N.O.No	215	120	70	B	NV	Org.	No	190,36	3.643	7.528
S30.HPA.511.B.N.N.No	215	70	70	B	NV	New.	No	175,60	3.287	7.151
S30.HPA.511.C.N.O.No	215	70	70	C	NV	Org.	No	234,88	2.711	7.045
S30.HPA.511.A.N.O.No	215	70	70	A	NV	Org.	No	226,33	2.730	6.939
S30.HPA.711.C.N.O.No	265	70	70	C	NV	Org.	No	230,35	2.773	7.053
S30.HPA.711.B.N.O.No	265	70	70	B	NV	Org.	No	224,98	2.760	6.955
S30.HPA.711.A.N.O.No	265	70	70	A	NV	Org.	No	221,80	2.793	6.947

Single family house 1960

The design and basic starting data of the reference building for existing single family house from 1960 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. For the ground slap in the case of 45 mm insulation it is over the concrete slap. In the case of 50 mm insulation or more it is below the concrete slap. The cost for the different solutions is shown in the next table.

Single family house 1960. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls, heavy		Walls, light		Ground slap	
	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K
0	95	0,346	0	0,439	0	0,514	(45)	0,369
1	120	0,286	50	0,305	45	0,337	50	0,353
2	145	0,244	100	0,240	70	0,283	100	0,241
3	170	0,213	200	0,176	95	0,244	150	0,183
4	195	0,189			115	0,219	200	0,148
5	240	0,152			140	0,195	275	0,114
6	265	0,138			165	0,176		
7	290	0,126			190	0,160		
8	315	0,116						
9	340	0,108						

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

New gas boiler

The new condensing gas boiler has an efficiency of 0,97 at full load and 1,06 at part load. The new boiler also includes new, well insulated DHW tank and new efficient control of the heating.

Solar heating

Solar heating is only relevant if the house is heated by gas. The solar heating also includes a larger DHW tank and connection to the heating of rooms. A panel area of 4,4 m^2 is used.

New air to water heat pump

The prices available are based on heat pumps tested at 7/35 C. The figures in brackets in the table are for the normal test temperature set of 7/45. In accordance with DS469 an air to water heat pump is required to cover the total heat demand down till an external temperature of -7 C without additional heating from an electric heating element. If connected to a floor heating system with a design supply temperature of 40 C the nominal heating power of the air to water heat pump at test temperatures should be at least 20 % higher than the design heat loss of the building at an external temperature of -12 C inclusive of the heating power needed for heating of domestic hot water. The additional design heating power for production of domestic hot water is estimated to 2,0 kW.

The air to water heat pump has a COP at normal test temperatures of 3,30. The COP used in the calculations is reduced to 3,10 to reflect the de-icing of the external air absorption coil. The heat pump control is on-off. The relative COP at 50 % part load is 0,90.

In the starting point a heat pump with a nominal output of 12 kW is needed. It is possibly to down size the heat pump when the building envelope is improved. From scenario S60.HPA.4031.A.N.N.No a heat pump with a nominal output of 10 kW is sufficient and thus used.

Loft
Prices are inclusive of removal of existing insulation. This is more cost efficient than relining of partly damaged, existing insulation.

Windows
Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020.

Natural ventilation
Air exchange rates in the case of natural ventilation are 0,45 l/s per m^2 gross floor area inclusive of infiltration.

Improved mechanical ventilation
The mechanical ventilation has an mechanical air exchange rate of 0,30 l/s per m^2 gross floor area in average due to demand control. The heat recovery efficiency is 0,85 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,00 kJ/m^3.

Infiltration
In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer
The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Solar cells, PV
The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 20^o and a horizontal cut off of 5^o. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

Existing single family house 1960. Investment in the energy saving measures, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations.

Building element		Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance DKK/unit (m^2)	Life time years
District heating unit		All	27.621	1.400	30
Gas boiler		16 kW	34.245	2.000	30
DHW tank			8.428		
Solar heating		4,4 m^2	39.837	1.000	25
incl. storage tank		6,6	47.269		
Heat pump		8 (6,0)	75.349	1.000	25
Air to water		10 (7,5)	80.227		
		12 (9,0)	85.089		
Loft		95 mm	206	0	40
		120	245		
		145	278		
		170	312		
		195	346		
		240	421		
		265	439		
		290	451		
		315	522		
		340	555		
Wall, heavy		0 mm	0	0	60
		50	1.413		
		100	1.780		
		200	2.454		
Wall, light		0 mm	0	0	60
		45	175		
		70	202		
		95	236		
		115	376		
		140	403		
		165	438		
		190	473		
Slap on ground		(45) mm	0	0	60
		50	919 (+0)		
		100	1.055 (+136)		
		150	1.184 (+265)		
		200	1.313 (+394)		
		275	1.491 (+572)		
Windows		C	3.718	0	40
		B	3.838		
		A	4.179		
Ventilation		Mechanical	93.939	1.000	25
PV	1:	1,14 kWp	35.066	0,5 % p.a.	20
	2:	2,28	66.654		
	3:	3,42	94.765		
	4:	4,56	119.398		
	5.	5,70	140.554		

The tables below and on next two pages list the packages of energy saving measures calculated for the existing single family house from 1960. Each package includes additional insulation on the loft, additional insulation on the external heavy walls, additional insulation on the light external walls, insulation of the ground slap, windows with specified energy class, new district heating unit alternatively new condensing gas or new air to water heat pump, mechanical ventilation as an alternative to the natural ventilation, solar heating (in the case of gas heating and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the single family house from 1960 with district heating, gas boiler or heat pump the requirement in the Danish Building Regulations 2010, BR10 is nearly at the point of cost optimality, showing a gap of 3,4 to -4,9 %. When the regulations in 2015 will include an requirement to use energy class B windows there is with to day's prices a small over-performance compared to the point of cost optimal with a gap of -1,6 to - 9,1 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased a little to - 4,8 % to -11,7 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

Existing single family house from 1960 with district heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft mm	W.h. mm	W.l mm	Slap. mm	Win. Class	Vent. Type	Heat Type	PV -	Energy kWh/m²	NPV-m DKK/m²	NPV-f DKK/m²
S60.DH.0000.T.N.O.No	0	0	0	(45)	Th.	NV	Org.	No	193,35	1.479	4.081
S60.DH.0000.C.N.O.No	95	0	0	(45)	C	NV	Org.	No	171,15	2.267	4.827
S60.DH.0000.B.N.O.No	95	0	0	(45)	B	NV	Org.	No	165,27	2.255	4.747
S60.DH.0000.A.N.O.No	95	0	0	(45)	A	NV	Org.	No	161,72	2.301	4.766
S60.DH.1000.B.N.O.No	120	0	0	(45)	B	NV	Org.	No	160,02	2.258	4.693
S60.DH.2000.B.N.O.No	145	0	0	(45)	B	NV	Org.	No	156,39	2.265	4.662
S60.DH.3000.B.N.O.No	170	0	0	(45)	B	NV	Org.	No	153,70	2.279	4.650
S60.DH.4000.B.N.O.No	195	0	0	(45)	B	NV	Org.	No	151,66	2.297	4.650
S60.DH.5000.B.N.O.No	240	0	0	(45)	B	NV	Org.	No	148,54	2.345	4.676
S60.DH.4100.B.N.O.No	195	50	0	(45)	B	NV	Org.	No	144,57	2.959	5.401
S60.DH.4010.B.N.O.No	195	0	45	(45)	B	NV	Org.	No	148,62	2.306	4.629
S60.DH.4020.B.N.O.No	195	0	70	(45)	B	NV	Org.	No	147,69	2.305	4.617
S60.DH.4030.B.N.O.No	195	0	95	(45)	B	NV	Org.	No	147,01	2.306	4.611
S60.DH.4040.B.N.O.No	195	0	115	(45)	B	NV	Org.	No	146,60	2.326	4.632
S60.DH.4031.B.N.O.No	195	0	95	50	B	NV	Org.	No	146,16	2.301	4.596
S60.DH.4032.B.N.O.No	195	0	95	100	B	NV	Org.	No	140,40	2.360	4.607
S60.DH.4031.B.M.O.No	195	0	95	50	B	MV	Org.	No	127,08	3.111	5.508
S60.DH.4031.B.N.N.No	195	0	95	50	B	NV	New	No	128,63	2.453	4.541
S60.DH.4031.B.N.N.PV1	195	0	95	50	B	NV	New	PV1	126,50	2.914	5.199
S60.DH.5033.C.N.N.No	240	0	95	150	C	NV	New	No	122,35	2.573	4.623
S60.DH.5033.B.N.N.No	240	0	95	150	B	NV	New	No	116,88	2.563	4.551
S60.DH.5033.A.N.N.No	240	0	95	150	A	NV	New	No	113,59	2.610	4.575

Existing single family house from 1960 with natural gas heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	W.h.	W.l	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	Type	-	kWh/m^2	DKK/m^2	DKK/m^2
S60.Gas.0000.T.N.O.No	0	0	0	(45)	Th.	NV	Org.	No	256,78	1.781	5.964
S60.Gas.0000.C.N.O.No	95	0	0	(45)	C	NV	Org.	No	226,15	2.544	6.489
S60.Gas.0000.B.N.O.No	95	0	0	(45)	B	NV	Org.	No	218,12	2.526	6.353
S60.Gas.0000.A.N.O.No	95	0	0	(45)	A	NV	Org.	No	213,28	2.568	6.338
S60.Gas.4000.A.N.O.No	195	0	0	(45)	A	NV	Org.	No	194,82	2.595	6.113
S60.Gas.5000.A.N.O.No	240	0	0	(45)	A	NV	Org.	No	190,53	2.640	6.108
S60.Gas.6000.A.N.O.No	265	0	0	(45)	A	NV	Org.	No	188,96	2.647	6.096
S60.Gas.7000.A.N.O.No	290	0	0	(45)	A	NV	Org.	No	187,59	2.651	6.081
S60.Gas.8000.A.N.O.No	315	0	0	(45)	A	NV	Org.	No	186,44	2.708	6. 137
S60.Gas.7100.A.N.O.No	290	50	0	(45)	A	NV	Org.	No	177,95	3.306	6.764
S60.Gas.7020.A.N.O.No	290	0	95	(45)	A	NV	Org.	No	182,19	2.655	6.010
S60.Gas.7030.A.N.O.No	290	0	95	(45)	A	NV	Org.	No	181,25	2.655	5.997
S60.Gas.7040.A.N.O.No	290	0	115	(45)	A	NV	Org.	No	180,71	2.675	6.015
S60.Gas.7031.A.N.O.No	290	0	95	50	A	NV	Org.	No	180,18	2.650	5.975
S60.Gas.7032.A.N.O.No	290	0	95	100	A	NV	Org.	No	172,32	2.703	5.931
S60.Gas.7033.A.N.O.No	290	0	95	150	A	NV	Org.	No	168,27	2.771	5.959
S60.Gas.7032.A.M.O.No	290	0	95	100	A	MV	Org.	No	144,04	3.760	7.263
S60.Gas.7032.A.N.N.No	290	0	95	100	A	NV	New	No	134,16	2.892	5.611
S60.Gas.7032.A.N.S.No	290	0	95	100	A	NV	Solar	No	117,49	3.356	6.159
S60.Gas.7032.A.N.N.PV1	290	0	95	100	A	NV	New	PV1	129,66	3.340	6.213
S60.Gas.5055.C.N.N.No	240	0	140	275	C	NV	New	No	138,71	3.129	5.971
S60.Gas.5055.B.N.N.No	240	0	140	275	B	NV	New	No	132,00	3.117	5.862
S60.Gas.5055.A.N.N.No	240	0	140	275	A	NV	New	No	127,75	3.163	5.860

Existing single family house from 1960 with air – water heat pump. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	W.h.	W.l	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
S60.HPA.0000.T.N.O.No	0	0	0	(45)	Th.	NV	Org.	No	273,19	1.753	6.432
S60.HPA.4031.B.N.O.No	195	0	95	50	B	NV	Org.	No	178,24	2.329	5.698
S60.HPA.4031.B.N.N.No	195	0	95	50	B	NV	New.	No	129,74	2.842	5.596
S60.HPA.4031.A.N.N.No	195	0	95	50	A	NV	New	No	126,09	2.844	5.543
S60.HPA.5031.A.N.N.No	240	0	95	50	A	NV	New.	No	123,70	2.898	5.574
S60.HPA.4032.A.N.N.No	195	0	95	100	A	NV	New.	No	120,56	2.908	5.538
S60.HPA.4033.A.N.N.No	195	0	95	150	A	NV	New.	No	117,09	2.979	5.573
S60.HPA.3033.A.N.N.No	170	0	95	150	A	NV	New.	No	119,41	2.961	5.587
S60.HPA.3033.B.N.N.No	170	0	95	150	B	NV	New.	No	122,28	2.955	5.622
S60.HPA.4032.A.N.N.PV1	195	0	95	100	A	NV	New.	PV1	98,21	3.255	5.747
S60.HPA.4032.A.N.N.PV2	195	0	95	100	A	NV	New.	PV2	75,87	3.555	5.886
S60.HPA.4032.A.N.N.PV3	195	0	95	100	A	NV	New.	PV3	59,41	3.842	6.087
S60.HPA.5055.C.N.N.No	195	0	95	100	C	NV	New.	No	118,76	3.205	5.881
S60.HPA.5055.B.N.N.No	195	0	95	100	B	NV	New.	No	112,47	3.193	5.770
S60.HPA.5055.A.N.N.No	195	0	95	100	A	NV	New.	No	108,73	3.240	5.772

Multifamily house 1930

The design and basic starting data of the reference building for existing multifamily house from 1930 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

Multifamily house 1930. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls, heavy		Basement slap	
	mm	W/m² K	mm	W/m² K	Mm	W/m² K
0	95	0,394	0	1,668	0	0,960
1	120	0,329	50	0,536	70	0,485
2	145	0,282	100	0,321		
3	170	0,235	200	0,178		
4	190	0,203				
5	215	0,178				
6	240	0,159				
7	265	0,144				
8	290	0,131				
9	315	0,120				
10	335	0,113				

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Loft

Prices are inclusive of removal of existing insulation. This is more cost efficient than relining of partly damaged, existing insulation.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020.

Balanced mechanical ventilation

The mechanical ventilation has an mechanical air exchange rate of 0,30 l/s per m^2 gross floor area in average due to demand control. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,50 kJ/m^3.

Infiltration

In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Multifamily house 1930. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations.

Building element	Size, insulation or type	Investment etc. DKK/unit (m²)	Maintenance etc. DKK/unit (m²)	Life time years
District heating installation and connection	All	93.350	1.500 + 150/kW	30
Loft	95 mm	187	0	40
	120	223		
	145	253		
	170	290		
	190	307		
	215	318		
	240	377		
	265	407		
	290	438		
	315	469		
	335	534		
Walls, heavy	0 mm	0	0	40
	50	1.201		
	100	1.513		
	200	2.086		
Basement slap	0 mm	0	0	40
	70	179		
Windows	C	3.380	0	40
	B	3.489		
	A	3.799		
Mechanical ventilation	Standard	673 per m²	5	25

The table on next page list the packages of energy saving measures calculated for the existing multifamily house from 1960 with district heating. Each package includes additional insulation on the loft, additional insulation on the external heavy walls, additional insulation of the basement slap, windows with specified energy class, new district heating unit and balanced mechanical ventilation with heat recovery as an alternative to the natural stack system. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

PV is not tested as a measure in the multifamily house from 1930, because it is known from the analysis of the existing multifamily house from 1960, that they are not cost efficient.

For the multifamily house from 1930 with district heating the requirement in the Danish Building Regulations 2010, BR10 is nearly at the point of cost optimality, showing a gap of 3,4 %. When the regulations in 2015 will include an requirement to use energy class B windows the result will be nearly exact at the point of cost optimal with a gap of -0,1 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased a little to - 2,3 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

Existing multifamily house from 1930 with district heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	Type	-	kWh/m^2	DKK/m^2	DKK/m^2
M30.DH.000.T.N.O.No	0	0	0	Th.	NV	Org.	No	176,27	1.337	3.640
M30.DH.000.B.N.O.No	95	0	0	B	NV	Org.	No	146,48	1.529	3.553
M30.DH.400.B.N.O.No	190	0	0	B	NV	Org.	No	142,34	1.526	3.504
M30.DH.500.B.N.O.No	215	0	0	B	NV	Org.	No	141,80	1.523	3.494
M30.DH.600.B.N.O.No	240	0	0	B	NV	Org.	No	141,38	1.534	3.503
M30.DH.510.B.N.O.No	215	50	0	B	NV	Org.	No	88,57	1.646	3.058
M30.DH.520.B.N.O.No	215	100	0	B	NV	Org.	No	79,01	1.710	3.031
M30.DH.530.B.N.O.No	215	200	0	B	NV	Org.	No	72,82	1.908	3.209
M30.DH.521.C.N.O.No	215	100	70	C	NV	Org.	No	73,35	1.696	2.949
M30.DH.521.B.N.O.No	215	100	70	B	NV	Org.	No	70,31	1.690	2.915
M30.DH.521.A.N.O.No	215	100	70	A	NV	Org.	No	69,39	1.711	2.924
M30.DH.521.B.N.N.No	215	100	70	B	NV	New.	No	68,30	1.730	2.937
M30.DH.521.B.M.O.No	215	100	70	B	MV	Org.	No	56,60	2.236	3.524
M30.DH.721.C.N.O.No	265	100	70	C	NV	Org.	No	72,68	1.712	2.962
M30.DH.721.B.N.O.No	265	100	70	B	NV	Org.	No	70,24	1.706	2.928
M30.DH.721.A.N.O.No	265	100	70	A	NV	Org.	No	68,72	1.727	2.937

Multifamily house 1960

The design and basic starting data of the reference building for existing multifamily house from 1960 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

Multifamily house 1960. Insulation thickness in the building elements and the related U-value of the construction.

Level	Loft		Walls, light		Basement slap	
	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	95	0,394	0	0,514	0	1,778
1	120	0,329	45	0,337	50	0,532
2	145	0,282	70	0,283	75	0,394
3	170	0,235	95	0,244	100	0,313
4	190	0,203	115	0,219		
5	215	0,178	140	0,195		
6	240	0,159	165	0,176		
7	265	0,144	190	0,160		
8	290	0,131				
9	315	0,120				
10	335	0,113				

District heating unit

For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Loft

Prices are inclusive of removal of existing insulation. This is more cost efficient than relining of partly damaged, existing insulation.

Light walls

Prices are only for the additional insulation. Original insulation is maintained in the existing construction.

Windows

Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020.

Balanced mechanical ventilation

The mechanical ventilation has an mechanical air exchange rate of 0,30 l/s per m^2 gross floor area in average due to demand control. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 1,50 kJ/m^3.

Infiltration

In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,20 l/s per m^2 gross floor area in average.

Solar cells, PV

The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 30^o and a horizontal cut off of 5^o. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

Multifamily house 1960. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT. 25 % VAT is added in the calculations.

Building element		Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance etc. DKK/unit (m^2)	Life time years
District heating installation and connection		All	104.742	1.500 + 150/kW	30
Loft		95 mm	187	0	40
		120	223		
		145	253		
		170	290		
		190	307		
		215	318		
		240	377		
		265	407		
		290	438		
		315	469		
		335	534		
Walls, light		0 mm	0	0	40
		45	157		
		70	181		
		95	213		
		115	339		
		140	363		
		165	394		
		190	426		
Basement slap		0 mm	0	0	40
		50	330		
		75	385		
		100	442		
Windows		C	3.380	0	40
		B	3.489		
		A	3.799		
Mechanical ventilation		Standard	598 per m^2	5	25
PV	1:	5,70 kWp	140.554	0,5 % p.a.	20
	X::	5,70 x X	140.554 x X		

The table below list the packages of energy saving measures calculated for the existing multifamily house from 1960 with district heating. Each package includes additional insulation on the loft, additional insulation on the external heavy walls, additional insulation of the basement slap, windows with specified energy class, new district heating unit, balanced mechanical ventilation with heat recovery as an alternative to the mechanical exhaust system and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the multifamily house from 1960 with district heating the requirement in the Danish Building Regulations 2010, BR10 is nearly at the point of cost optimality, showing a gap of 3,8 %. When the regulations in 2015 will include an requirement to use energy class B windows the result will be nearly at the point of cost optimal with a gap of -1,5 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased a little to - 4,6 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

Existing multifamily house from 1960 with district heating. Energy saving measures, primary energy consumption, macro economical and financial net present value.

Code	Loft	Wall	Slap.	Win.	Vent.	Heat	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
M60.DH.000.T.E.O.No	0	0	0	Th.	ME	Org.	No	123,47	943	2.679
M60.DH.000.C.E.O.No	95	0	0	C	ME	Org.	No	105,81	1.379	3.027
M60.DH.400.C.E.O.No	190	0	0	C	ME	Org.	No	101,65	1.375	2.977
M60.DH.500.C.E.O.No	215	0	0	C	ME	Org.	No	101,11	1.373	2.969
M60.DH.600.C.E.O.No	240	0	0	C	ME	Org.	No	100,70	1.384	2.978
M60.DH.510.C.E.O.No	215	45	0	C	ME	Org.	No	95,56	1.378	2.914
M60.DH.520.C.E.O.No	215	70	0	C	ME	Org.	No	93,88	1.372	2.887
M60.DH.530.C.E.O.No	215	95	0	C	ME	Org.	No	92,67	1.373	2.875
M60.DH.540.C.E.O.No	215	115	0	C	ME	Org.	No	91,90	1.404	2.905
M60.DH.531.C.E.O.No	215	95	50	C	ME	Org.	No	84,96	1.357	2.763
M60.DH.532.C.E.O.No	215	95	75	C	ME	Org.	No	83,44	1.355	2.743
M60.DH.533.C.E.O.No	215	95	100	C	ME	Org.	No	82,44	1.358	2.736
M60.DH.533.B.E.O.No	215	95	100	B	ME	Org.	No	78,42	1.344	2.676
M60.DH.533.A.E.O.No	215	95	100	A	ME	Org.	No	76,05	1.375	2.689
M60.DH.533.B.M.O.No	215	95	100	B	MV	Org.	No	50,67	1.761	2.866
M60.DH.533.B.E.N.No	215	95	100	B	ME	New.	No	75,26	1.354	2.646
M60.DH.533.B.E.N.PV1	215	95	100	B	ME	New.	PV1	71,94	1.392	2.651
M60.DH.752.C.E.N.No	265	140	75	C	ME	New.	No	78,13	1.412	2.750
M60.DH.752.B.E.N.No	265	140	75	B	ME	New.	No	74,14	1.399	2.690
M60.DH.752.A.E.N.No	265	140	75	A	ME	New.	No	71,82	1.430	2.703

Office building 1960

The design and basic starting data of the reference building for existing office buildings from 1960 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The cost for the different solutions is shown in the next table.

Office building 1960. Insulation thickness in the building elements and the related U-value of the constructions.

Level	Flat roof		Walls, heavy		Walls, light		Basement slap	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	100	0,341	0	1,668	0	0,514	0	1,778
1	180	0,196	50	0,536	45	0,337	50	0,532
2	230	0,155	100	0,321	70	0,283	75	0,394
3	280	0,128	200	0,178	95	0,244	100	0,313
4	340	0,106			115	0,219		
5	440	0,082			140	0,195		
6	540	0,067			165	0,176		
					190	0,160		

District heating unit
For district heating the price includes the installation of the district heating unit and also the connection to the main pipes inclusive of meter. The annual cost for maintenance etc. includes both the annual fixed fee for the connection and the maintenance costs.

Roof
Prices are inclusive of removal of existing insulation. This is more cost efficient than relining of partly damaged, existing insulation.

Light walls
Prices are only for the additional insulation. Original insulation is maintained in the existing construction.

Windows
Windows are energy class C, B and A in accordance with the requirements in BR 10 for 2010, 2015 and 2020. The cost for windows is 10 % lower compared to small buildings.

New standard mechanical ventilation system
The mechanical ventilation is constant 1,80 l/s per m^2 gross floor area. The heat recovery efficiency is 0,70 and the minimum inlet temperature is 18 ^{o}C. The specific power for air transportation, SEL is 1,80 kJ/m^3.

New improved mechanical ventilation system
The mechanical ventilation has an average air exchange rate of 0,90 l/s per m^2 gross floor area due to demand control. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^{o}C. The specific power for air transportation, SEL is 1,20 kJ/m^3.

Infiltration
In combination with the mechanical ventilation the infiltration in the base cases and in the BR 10 case is 0,13 l/s per m^2 gross floor area. In relation to Low Energy Building 2015 the infiltration is 0,10 l/s per m^2 gross floor area. In relation to Building 2020 the infiltration is 0,07 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 1,80 l/s per m^2 gross floor area in average. In relation to the improved ventilation the air exchange rate in average is up till 2,40 l/s per m^2 gross floor area and includes also airing at night.

Office building 1960. Investment in the energy related building elements, maintenance costs and life time of the elements. Investments and cost in the table are exclusive of VAT.

Building element		Size, insulation or type	Investment etc. DKK/unit (m^2)	Maintenance etc. DKK/unit (m^2)	Life time years
District heating installation and connection		All	111.996	1.500 + 150/kW	30
Flat roof		100 mm	395	0	40
		180	609		
		230	698		
		280	778		
		340	892		
		440	1.033		
		540	1.190		
Walls, heavy		0 mm	0	0	40
		50	1.201		
		100	1.513		
		200	2.086		
Walls, light		0 mm	0	0	40
		45	157		
		70	181		
		95	213		
		115	339		
		140	363		
		165	394		
		190	426		
Basement slap		0 mm	0	0	40
		50	330		
		75	385		
		100	442		
Windows		C	3.380	0	40
		B	3.489		
		A	3.799		
Mechanical ventilation		Standard central	175.000 total	5 (13.760)	25
		Improved plant	2.000 per m^2		
Lighting		Standard	308	0	25
		Improved	450		
PV	1:	5,70 kWp	140.554	0,5 % p.a.	20
	X::	5,70 x X	140.554 x X		

Solar cells, PV

The solar cell, PV system has a peak power of 140 Wp/m^2 and a system efficiency, Rp of 0,75. The cells are mounted on the roof in a rack with a slope of 45^o and a horizontal cut off of 15^o due to the need of having the racks in more rows. Maintenance of PV also includes the need to change the inverter due to shorter lifetime of the inverter compared to the solar panels.

New standard lighting system

Installed power in the office areas is 8 W/m^2. There are automatic daylight control on-off in 2 zones from the façade and one zone in the middle..

New improved lighting system

Installed power in office areas is 6 W/m^2. There is daylight dimming control and present sensors in 2 zones from the façade and one zone in the middle.

The table on next page list the packages of energy saving measures calculated for the existing office building from 1960 with district heating. Each package includes additional insulation on the roof, additional insulation on the external heavy walls, additional insulation on the light external walls, additional insulation of the basement slap, windows with specified energy class, new district heating unit, standard or improved update of the balanced mechanical ventilation, standard or improved update of the lighting system and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the office building from 1960 with district heating the requirement in the Danish Building Regulations 2010, BR10 is nearly at the point of cost optimality, showing a gap of 3,7 %. When the regulations in 2015 will include an requirement to use energy class B windows the result will be nearly at the point of cost optimal with a gap of -2,1 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased a little to - 5,7 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

The difference in financial net present value between the starting point in "OC0.DH.0000.C.O.O.No", where just windows are changed and roof insulation are re-established, and the cost optimal solution in "O60.DH.0133. B.S.I.No" is 728 DKK/m^2. This value will be used later in relation to the sensitivity analysis.

Existing office building from 1960 with district heating. Energy saving measures, primary energy consumption and financial net present value.

Code	Roof	W.h.	W.l	Slap.	Win.	Vent.	Light	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
O60.DH.0000.T.O.O.No	0	0	0	0	Th.	Org.	Org.	No	231,90	1.356	2.948
O60.DH.0000.C.O.O.No	100	0	0	0	C	Org.	Org.	No	202,33	1.918	3.353
O60.DH.0000.B.O.O.No	100	0	0	0	B	Org.	Org.	No	196,37	1.906	3.294
O60.DH.0000.A.O.O.No	100	0	0	0	A	Org.	Org.	No	193,21	1.949	3.319
O60.DH.1000.B.O.O.No	180	0	0	0	B	Org.	Org.	No	194,15	1.929	3.304
O60.DH.2000.B.O.O.No	230	0	0	0	B	Org.	Org.	No	193, 25	1.940	3.312
O60.DH.0100.B.O.O.No	100	50	0	0	B	Org.	Org.	No	184,10	1.954	3.273
O60.DH.0200.B.O.O.No	100	100	0	0	B	Org.	Org.	No	181,78	1.971	3.277
O60.DH.0010.B.O.O.No	100	0	45	0	B	Org.	Org.	No	194,10	1.911	3.286
O60.DH.0020.B.O.O.No	100	0	70	0	B	Org.	Org.	No	193,42	1.910	3.282
O60.DH.0030.B.O.O.No	100	0	95	0	B	Org.	Org.	No	192,92	1.912	3.280
O60.DH.0040.B.O.O.No	100	0	115	0	B	Org.	Org.	No	191,85	1.920	3.283
O60.DH.0031.B.O.O.No	100	0	95	50	B	Org.	Org.	No	186,71	1.927	3.261
O60.DH.0032.B.O.O.No	100	0	95	75	B	Org.	Org.	No	185,47	1.930	3.256
O60.DH.0033.B.O.O.No	100	0	95	100	B	Org.	Org.	No	184,65	1.934	3.256
O60.DH.0030.B.S.O.No	100	0	95	0	B	St.	Org.	No	158,93	1.702	2.863
O60.DH.0030.B.I.O.No	100	0	95	0	B	Imp.	Org.	No	134,36	3.041	4.026
O60.DH.0030.B.O.S.No	100	0	95	0	B	Org.	Std.	No	166,26	2.078	3.225
O60.DH.0030.B.O.I.No	100	0	95	0	B	Org.	Imp.	No	145,68	2.121	3.097
O60.DH.0133.B.O.O.No	100	50	95	100	B	Org.	Org.	No	173,29	1.986	3.246
O60.DH.0133.B.S.O.No	100	50	95	100	B	Std.	Org.	No	138,98	1.775	2.825
O60.DH.0133.B.S.I.No	100	50	95	100	B	Std.	Imp.	No	90,21	1.978	2.625
O60.DH.1133.B.S.I.No	180	50	95	100	B	Std.	Imp.	No	87,93	2.000	2.635
O60.DH.0233.B.S.I.No	100	100	95	100	B	Std.	Imp.	No	87,88	1.996	2.630
O60.DH.0143.B.S.I.No	100	50	115	100	B	Std.	Imp.	No	89,91	1.992	2.637
O60.DH.0133.B.S.I.PV5	100	50	95	100	B	Std.	Imp.	PV5	71,89	2.135	2.638
O60.DH.0133.B.S.I.PV10	100	50	95	100	B	Std.	Imp.	PV10	53,57	2.293	2.652
O60.DH.0252.C.S.I.No	100	100	140	75	C	Std.	Imp.	No	93,52	2.016	2.681
O60.DH.0252.B.S.I.No	100	100	140	75	B	Std.	Imp.	No	88,35	2.007	2.644
O60.DH.0252.A.S.I.No	100	100	140	75	A	Std.	Imp.	No	85,10	2.049	2.667

Office building 1980

The design and basic starting data of the reference building for existing office buildings from 1980 is described in the annex.

In the table below are listed the relevant insulation thickness and the related U-values. The table only differs from the table for the 1960 office building in relation to the heavy and light external walls being better insulated from the start in the 1980 office building.

The cost for the different solutions is the same as for the 1960 office building.

Office building 1980. Insulation thickness in the building elements and the related U-value of the construction.

Level	Flat roof		Walls, heavy		Walls, light		Basement slap	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	100	0,341	0	0,439	0	0,398	0	1,778
1	180	0,196	50	0,305	45	0,283	50	0,532
2	230	0,155	100	0,240	70	0,244	75	0,394
3	280	0,128	200	0,176	95	0,214	100	0,313
4	340	0,106			115	0,195		
5	440	0,082			140	0,176		
6	540	0,067			165	0,160		
					190	0,146		

The table on next page list the packages of energy saving measures calculated for the existing office building from 1980 with district heating. Each package includes additional insulation on the roof, additional insulation on the external heavy walls, additional insulation on the light external walls, additional insulation of the basement slap, windows with specified energy class, new district heating unit, standard or improved update of the balanced mechanical ventilation, standard or improved update of the lighting system and possibly PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

For the office building from 1980 with district heating the requirement in the Danish Building Regulations 2010, BR10 passes the point of cost optimality, showing a gap of - 6,6 %. When the regulations in 2015 will include an requirement to use energy class B windows the gap will increase a little to - 10,8 %. When the regulation in 2020 are further tightened to use energy class A windows the gap is increased further to - 13,0 %. The calculated over-performance is based on today's prices and will possibly be levelled out when becoming a common minimum requirement due to development in energy and construction costs.

The difference in financial net present value between the starting point in "O80.DH.0000.C.O.O.No", where just windows are changed and roof insulation are re-established, and the cost optimal solution in "O80.DH.0023. B.S.O.No" is 119 DKK/m^2. This value will be used later in relation to the sensitivity analysis.

The 1980 office building is from the start constructed to be partly energy efficient both in relation to the solutions in the building envelope and in relation to the installations. It limits the possibility to suggest cost efficient energy saving measures in the building.

Existing office building from 1980 with district heating. Energy saving measures, primary energy consumption and financial net present value.

Code	Roof	W.h.	W.l	Slap.	Win.	Vent.	Light	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	Type	-	kWh/m²	DKK/m²	DKK/m²
O80.DH.0000.T.O.O.No	0	0	0	0	Th.	Org.	Org.	No	181,30	1.024	2.302
O80.DH.0000.C.O.O.No	100	0	0	0	C	Org.	Org.	No	153,53	1.594	2.714
O80.DH.0000.B.O.O.No	100	0	0	0	B	Org.	Org.	No	148,23	1.584	2.674
O80.DH.0000.A.O.O.No	100	0	0	0	A	Org.	Org.	No	145,08	1.626	2.699
O80.DH.1000.B.O.O.No	180	0	0	0	B	Org.	Org.	No	146,04	1.606	2.685
O80.DH.0100.B.O.O.No	100	50	0	0	B	Org.	Org.	No	146,83	1.694	2.777
O80.DH.0010.B.O.O.No	100	0	45	0	B	Org.	Org.	No	146,77	1.713	2.677
O80.DH.0020.B.O.O.No	100	0	70	0	B	Org.	Org.	No	146,26	1.713	2.674
O80.DH.0030.B.O.O.No	100	0	95	0	B	Org.	Org.	No	145,90	1.715	2.674
O80.DH.0021.B.O.O.No	100	0	70	50	B	Org.	Org.	No	140,65	1.732	2.662
O80.DH.0022.B.O.O.No	100	0	70	75	B	Org.	Org.	No	139,67	1.735	2.661
O80.DH.0023.B.O.O.No	100	0	70	100	B	Org.	Org.	No	138,84	1.739	2.661
O80.DH.0023.B.S.O.No	100	0	70	100	B	St.	Org.	No	130,08	1.734	2.595
O80.DH.0023.B.O.S.No	100	0	70	100	B	Org.	St.	No	124,04	1.952	2.751
O80.DH.0023.B.O.O.PV10	100	0	70	100	B	Org.	Org.	PV10;	102,19	2.054	2.687
O80.DH.0032.C.O.S.No	100	0	70	100	C	St.	St.	No	121,51	1.956	2.729
O80.DH.0032.B.O.S.No	100	0	70	100	B	St.	St.	No	116,08	1.946	2.688
O80.DH.0032.A.O.S.No	100	0	70	100	A	St.	St.	No	113,18	1.989	2.716

Sensitivity analysis

Sensitivity analysis are performed with a higher energy price development of + 2,0 % p.a. and with a higher discount rate and interest rate of +2,0 % p.a. The analysis is performed for the office building with district heating constructed in 1960 and 1980, see table at this page and on next page.

Existing office building from 1960 with district heating. Energy saving measures, primary energy consumption and financial net present value. Sensitivity analysis.

		Energy + 2,0 % p.a.		Rates + 2,0 % p.a.	
Code	Energy	NPV-m	NPV-f	NPV-m	NPV-f
	kWh/m^2	DKK/m^2	DKK/m^2	DKK/m^2	DKK/m^2
O60.DH.0000.T.O.O.No	231,90	1.655	3.645	1.130	2.426
O60.DH.0000.C.O.O.No	202,33	2.180	3.973	1.809	2.977
O60.DH.0000.B.O.O.No	196,37	2.161	3.895	1.805	2.934
O60.DH.0000.A.O.O.No	193,21	2.199	3.912	1.858	2.973
O60.DH.1000.B.O.O.No	194,15	2.180	3.900	1.834	2.954
O60.DH.2000.B.O.O.No	193, 25	2.191	3.906	1.847	2.964
O60.DH.0100.B.O.O.No	184,10	2.192	3.841	1.886	2.960
O60.DH.0200.B.O.O.No	181,78	2.207	3.840	1.912	2.976
O60.DH.0010.B.O.O.No	194,10	2.163	3.882	1.816	2.935
O60.DH.0020.B.O.O.No	193,42	2.161	3.875	1.816	2.932
O60.DH.0030.B.O.O.No	192,92	2.162	3.873	1.819	2.933
O60.DH.0040.B.O.O.No	191,85	2.169	3.873	1.831	2.941
O60.DH.0031.B.O.O.No	186,71	2.169	3.837	1.850	2.936
O60.DH.0032.B.O.O.No	185,47	2.170	3.829	1.855	2.935
O60.DH.0033.B.O.O.No	184,65	2.174	3.827	1.862	2.939
O60.DH.0030.B.S.O.No	158,93	1.895	3.346	1.654	2.600
O60.DH.0030.B.I.O.No	134,36	3.212	4.442	3.068	3.869
O60.DH.0030.B.O.S.No	166,26	2.304	3.740	2.013	2.947
O60.DH.0030.B.O.I.No	145,68	2.330	3.551	2.075	2.869
O60.DH.0133.B.O.O.No	173,29	2.211	3.786	1.948	2.973
O60.DH.0133.B.S.O.No	138,98	1.943	3.255	1.782	2.637
O60.DH.0133.B.S.I.No	90,21	2.103	2.912	2.033	2.559
O60.DH.1133.B.S.I.No	87,93	2.123	2.916	2.062	2.578
O60.DH.0233.B.S.I.No	87,88	2.118	2.911	2.058	2.574
O60.DH.0143.B.S.I.No	89,91	2.116	2.924	2.049	2.575
O60.DH.0133.B.S.I.PV5	71,89	2.248	2.878	2.200	2.608
O60.DH.0133.B.S.I.PV10	53,57	2.393	2.844	2.366	2.657
O60.DH.0252.C.S.I.No	93,52	2.145	2.977	2.072	2.613
O60.DH.0252.B.S.I.No	88,35	2.129	2.926	2.071	2.589
O60.DH.0252.A.S.I.No	85,10	2.167	2.941	2.123	2.627

There is a very small change in the cost optimum point in the direction of better energy efficiency in the case where the additional energy price development are + 2,0 p.a. The opposite cannot be observed in the case where there is an additional development of the rates of +2,0 p.a. It probably has to do with the very small changes compared to the resolutions in the calculation coming from the steps in the energy efficiency e.g. in relation to available insulation thickness.

The difference in financial net present value between the starting point in "O60.DH.0000.C.O.O.No" and the cost optimal solution in "O60.DH.0133. B.S.I.No" changes with the energy price development and with the development in rates. In the case where the additional energy price development are + 2,0 p.a. the difference increases from 728 DKK/m^2 to 1.062 DKK/m^2. In the case where the additional rate development are + 2,0 p.a. the difference decreases to 418 DKK/m^2.

Existing office building from 1980 with district heating. Energy saving measures, primary energy consumption and financial net present value. Sensitivity analysis.

		Energy + 2,0 % p.a.		Rates + 2,0 % p.a.	
Code	Energy	NPV-m	NPV-f	NPV-m	NPV-f
	kWh/m^2	DKK/m^2	DKK/m^2	DKK/m^2	DKK/m^2
O80.DH.0000.T.O.O.No	181,30	1.249	2.847	853	1.894
O80.DH.0000.C.O.O.No	153,53	1.784	3.184	1.538	2.451
O80.DH.0000.B.O.O.No	148,23	1.767	3.130	1.536	2.425
O80.DH.0000.A.O.O.No	145,08	1.805	3.146	1.589	2.463
O80.DH.1000.B.O.O.No	146,04	1.787	3.135	1.565	2.444
O80.DH.0100.B.O.O.No	146,83	1.876	3.229	1.671	2.553
O80.DH.0010.B.O.O.No	146,77	1.895	3.129	1.693	2.434
O80.DH.0020.B.O.O.No	146,26	1.894	3.124	1.693	2.432
O80.DH.0030.B.O.O.No	145,90	1.895	3.123	1.697	2.434
O80.DH.0021.B.O.O.No	140,65	1.905	3.097	1.728	2.442
O80.DH.0022.B.O.O.No	139,67	1.907	3.093	1.734	2.444
O80.DH.0023.B.O.O.No	138,84	1.911	3.091	1.741	2.447
O80.DH.0023.B.S.O.No	130,08	1.894	2.998	1.746	2.403
O80.DH.0023.B.O.S.No	124,04	2.110	3.139	1.974	2.581
O80.DH.0023.B.O.O.PV10	102,19	2.200	3.023	2.074	2.545
O80.DH.0032.C.O.S.No	121,51	2.110	3.106	1.979	2.564
O80.DH.0032.B.O.S.No	116,08	2.093	3.051	1.977	2.537
O80.DH.0032.A.O.S.No	113,18	2.133	3.071	2.030	2.578

No change in the cost optimum point can be observed in relation to additional energy price development or in relation to additional development of the rates.

The difference in financial net present value between the starting point in "O80.DH.0000.C.O.O.No" and the cost optimal solution in "O80.DH.0023. B.S.O.No" changes with the energy price development and with the development in rates. In the case where the additional energy price development are + 2,0 p.a. the difference increases from 119 DKK/m^2 to 186 DKK/m^2. In the case where the additional rate development are + 2,0 p.a. the difference decreases to 48 DKK/m^2.

Compared to the new office buildings no definite shift can be observed in to the cost efficiency of PV in relation to an increased energy price development of + 2,0 % p.a.

References

The reference list includes publications relevant to this report. The publications can be in English or in Danish. If there is an English version of a publication the Danish version of the same publication will not be on the list. If a publication is only in Danish the translation of the title into English is in brackets after the Danish title.

A large number of European Standards (EN's) is also used in relation to the Danish regulations. They can easily be found on the home page of CEN or the national standardisation bodies inclusive of Danish Standards and are for practical reasons not listed here.

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DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast).

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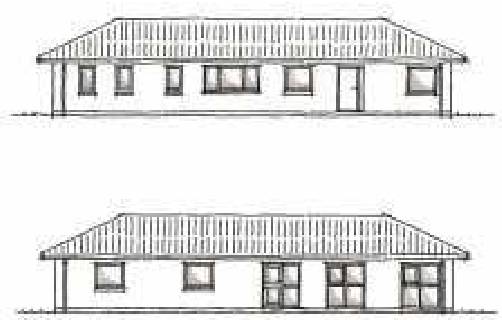
Appendix: Reference buildings

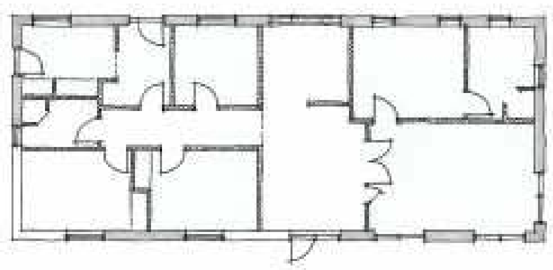
New buildings

New single-family house



North and South facade

East and West gable



Plan

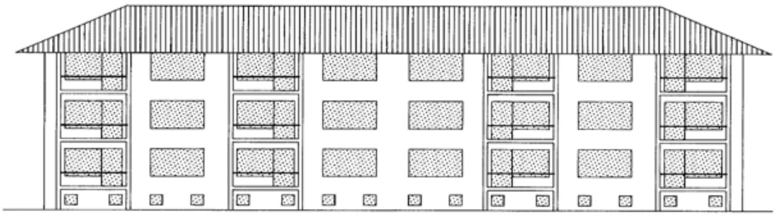
The house has a gross floor area of 149,6 m² and includes living room, dining room, 4 bedrooms, kitchen, utility room and two bathrooms.

There is an open attic with insulation on the loft. The external wall is an insulated cavity wall with 100 mm light concrete inner wall and a ½ stone brick in the external façade. The top of the foundations are made of insulated light concrete aggregate blocks. The slap on ground is 100 mm concrete with floor heating and insulation below the concrete. The partition walls are made of light concrete blocks. The window area is 22,0 % compared to the floor area.

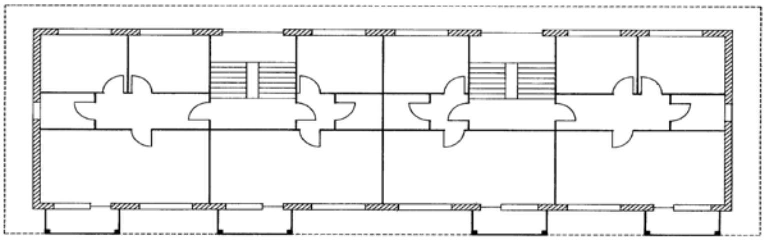
At the starting point there are natural ventilation in the house with external air vents in the living rooms, exhaust ducts from kitchen and bathrooms and a cooker hood in the kitchen.

The heat supply is either district heating or ground coupled heat pump. The ground coupled heat pump is on-off controlled and has a COP of 3,2 at test temperatures 0/45 ^{o}C.

Pipes and fittings are insulated in accordance with DS 452.



Facade



N

Plan

South facade and plan

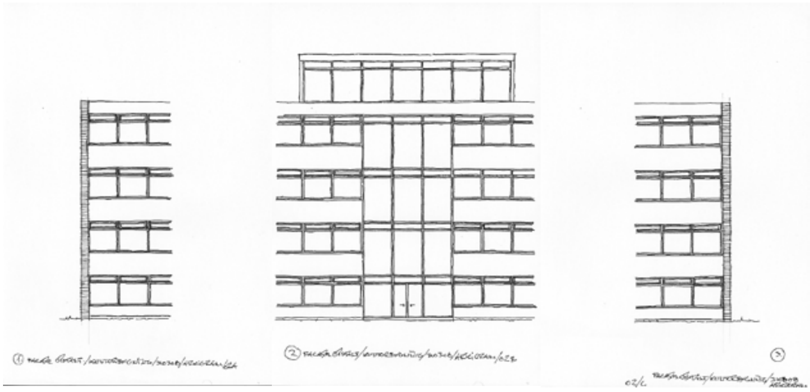
The building is 3 storey with a heated gross floor area of 1080 m², 360 m² gross floor area per storey. There are 6 small apartments of 66 m² each and 6 large apartments of 91 m² each. The window area is 22,5 % compared to the floor area. The major part of window area in the flats is facing South. There are also large glazed areas in the stairways is facing North.

There is an open attic with insulation on the loft. The external wall is an insulated cavity wall with 100 - 150 mm concrete inner wall and a ½ stone brick in the external façade. The basement slap is 185 mm hollow core concrete with floor heating on top. There is 50 mm insulation between the floor heating and the concrete slap. The apartment partition walls are made of concrete elements. The interior partition walls in the flats are gypsum plate walls.

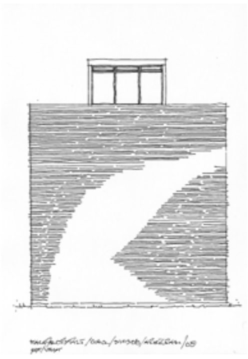
At the starting point there are demand controlled mechanical balanced ventilation with heat recovery in the house with air inlet in the living rooms, exhaust from kitchen and bathrooms and a cooker hood in the kitchen.

The heat supply is district heating. There are horizontal distribution pipes in the basement and vertical circulation of domestic hot water till the flats on first floor. Pipes and fittings are insulated in accordance with DS 452.

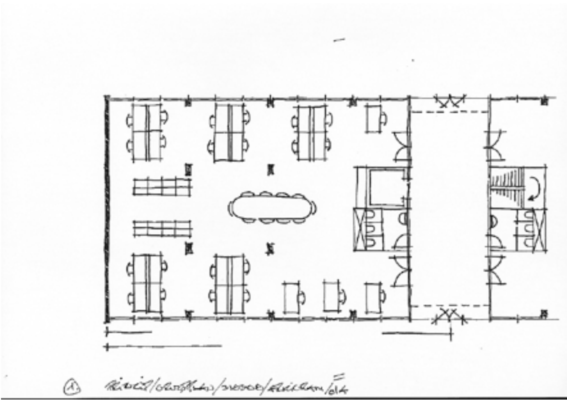
New office building



Facades



Gable



Floor plan

The office building is 4 storey and has a heated gross floor area of 3283 m². The building is 50,7 m x 16,4 m. There is an unheated technic room at the roof and an unheated basement. The ceiling height is 2,80 m along the facades and 2,50 m in the centre of the building to allow space for ventilation ducts. The storey height is 3,60 m. The facades has large window area with airing windows at the top, large sealed glazing in the middle and in insulated lower wall below. In the stairway room all squares in the facade is glazed. The faced towards North and South are identical. The window area is 27,2 % compared to the floor area and 44 % of the total façade area inclusive of gables.

The roof is flat with insulation and felt on top of the concrete slaps. The gable walls are insulated cavity walls with 100 - 150 mm concrete inner wall and a ½ stone brick in the external façade. The basement slap is 185 mm hollow core concrete with flooring on top. The load baring partition walls are made of concrete elements. The rest of the partition walls are made of gypsum plates.

There are automatic controlled external solar shading with a solar reduction factor of 0,20 in front of all windows.

At the starting point there are balanced mechanical ventilation with heat recovery in the offices at a constant ventilation rate of 1,8 liter/sek. per m² gross floor area. The heat recovery efficiency is 0,70 and the power needed for air transportation, SEL is 1,8 kJ/m³. The ventilation also operates at night in hot summer periods. The airing windows are automatically controlled with the possibility to open during operation hours. There is mechanical exhaust from the toilets without heat recovery.

The lighting level is 200 lux in the offices and 50 lux in other rooms. The installed power is 8 W per m² gross floor area in the offices and 5 W per m² in other rooms. The lighting fixtures are automatically daylight controlled in three rows from the façade. The lighting in the stairway is always on. In night there are light in the stairway and in the escalator plus in selected fixtures in the stairway room and in the core zone of the offices.

The office building is connected to the district heating network and heated by radiators. There are vertical distribution pipes for heating and hot water to both sides of the stairway. There is circulation on the hot water. Pipes and fittings are insulated in accordance with DS 452.

Existing buildings

Single-family house 1930

The house is a bungalow from 1932 with a gross floor area of 103 m² on the first floor. It includes living room, dining room, bedroom, kitchen and bathroom. The basement is with full ceiling height and half below, half above the exterior terrain level. The window area is 16 % compared to the floor area. Windows are at the starting point installed I the 60's and have double glazing.

There is an open attic with insulation on the loft. At the starting point there is 95 mm insulation on the loft installed in the late 70's. The external wall is an un-insulated cavity wall with solid brickwork around window and door openings. The basement slap is a wood construction without thermal insulation. The basement wall and floor is made of concrete without any insulation

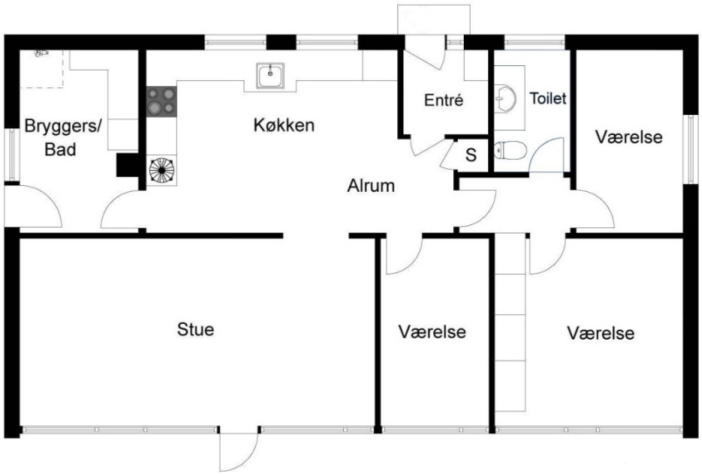
At the starting point there is natural ventilation in the house without any specific ventilation provisions. The airtightness of the building envelop is lacking especial around windows and doors. There is a cooker hood in the kitchen.

The heat supply is either district heating, gas boiler or external air heat pump. The existing gas boiler has an efficiency of 0,90 at full load and 0,88 at part load. The existing heat pump is on-off controlled and has a COP of 2,5 at test temperatures 7/45 ^{o}C. In all cases there is at the starting point lack of automatic control.

Pipes and fittings are insulated with 10 mm insulation. There is a 200 liter DHW tank insulated with 30 mm.

Single-family house 1960

Facade to the North



Plan

The house is with a gross floor area of 108 m². It includes living room, dining room, 3 bedroom, kitchen, utility room and bathroom. The window area is 22 % compared to the floor area.

There is an open attic with insulation on the loft. At the starting point there is 95 mm insulation on the loft installed in the late 70's. The external wall is an cavity wall with 75 mm insulation solid brickwork around window and door openings. The South façade is a light wall with 95 mm insulation. The slap on ground is a concrete slap with a wooden floor on top. There is 50 mm insulation between the concrete and the floring

At the starting point there is natural ventilation in the house with exhaust ducts from kitchen and bathroom but no specific provisions for air supply. The airtightness of the building envelop is lacking especial around windows and doors. There is a cooker hood in the kitchen.

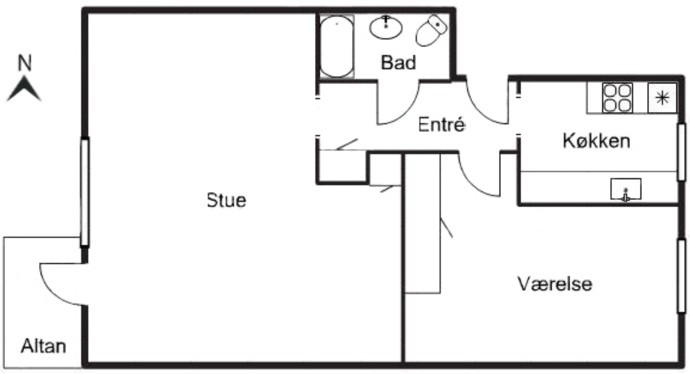
The heat supply is either district heating, gas boiler or external air heat pump. The existing gas boiler has an efficiency of 0,90 at full load and 0,88 at part load. The existing heat pump is on-off controlled and has a COP of 2,5 at test temperatures 7/45 ^{o}C. In all cases there is at the starting point lack of automatic control.

Pipes and fittings are insulated with 20 mm insulation. There is a 200 liter DHW tank insulated with 30 mm.

Multifamily house 1930

South facade

North facade



Plan

The building is 4 storey with 24 flats and a heated gross floor area of 1664 m². Each flat includes living room, bedroom, kitchen and bathroom. The window area is 12 % compared to the floor area. The windows are installed in the 80's and are with double glazing. There is an un-heated basement.

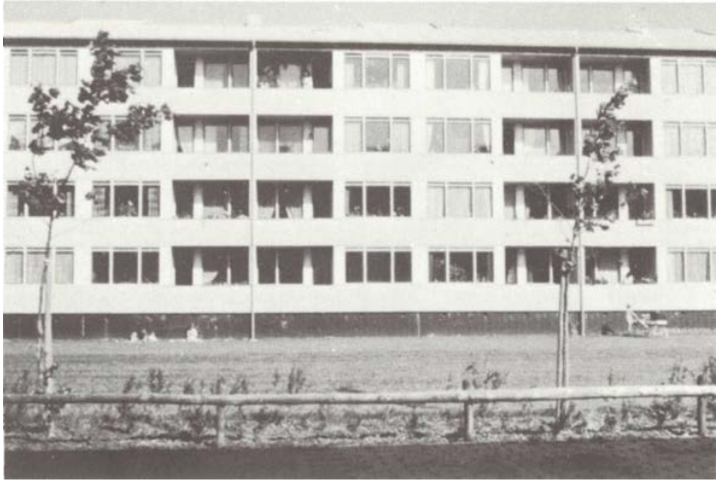
There is an open attic with insulation on the loft. At the starting point there is 95 mm insulation on the loft installed in the late 70's. The external wall is an un-insulated cavity wall with solid brickwork around window and door openings. The basement slap is a wood construction without thermal insulation. The basement wall and floor is made of concrete without any insulation

At the starting point there is natural ventilation in the house with exhaust ducts from kitchens and bathrooms but no specific provisions for air supply. The airtightness of the building envelop is lacking especial around windows and doors. There is a cooker hood in the kitchens.

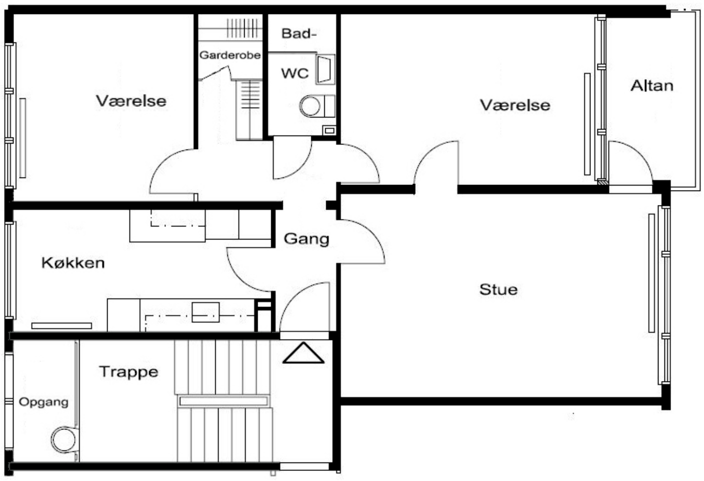
The heat supply is district heating. There are horizontal distribution pipes in the basement and vertical circulation of domestic hot water till the flats on second floor.

Pipes and fittings are insulated with 20 mm insulation. There is a 1000 liter DHW tank insulated with 30 mm.

Multifamily house 1960



North facade



Plan of flat

The building is 4 storey with 40 flats and a heated gross floor area of 3640 m². Each flat includes living room, 2 bedrooms, kitchen and bathroom. The window area is 17 % compared to the floor area. The windows are with double glazing. There is an un-heated basement.

There is an open attic with insulation on the concrete slap. At the starting point there is 95 mm insulation on the loft. The external wall is a light wooden construction with 95 mm insulation. The partition walls are made of concrete. The basement slap is a concrete construction without thermal insulation. The basement wall and floor is made of concrete without any insulation

At the starting point there is mechanical exhaust in the house with exhaust from kitchens and bathrooms but no specific provisions for air supply. The airtightness of the building envelop is lacking especial around windows and doors. There is a cooker hood in the kitchens.

The heat supply is district heating. There are horizontal distribution pipes in the basement and vertical circulation of domestic hot water till the flats on the second floor.

Pipes and fittings are insulated with 20 mm insulation. There is a 1000 liter DHW tank insulated with 30 mm.

Office building 1960

The office building from 1960 has basically the same design and type of installations as the office building from 1980 and as the new office building. But the energy efficiency of the constructions and installations are different.

The flat roof is with 100 mm insulation and felt on top of the concrete slaps. The windows are with double glazing. The lower wall below the windows is with 95 mm insulation.The gable walls are massive walls with 100 - 150 mm concrete inner wall and a ½ stone brick in the external façade. The basement slap is 185 mm hollow core concrete with flooring on top. There is no insulation in the gable walls or in the basement slap. The load baring partition walls are made of concrete elements. The rest of the partition walls are made of gypsum plates.

There are automatic controlled external solar shading with a solar reduction factor of 0,20 in front of all windows.

At the starting point there are balanced mechanical ventilation with heat recovery in the offices at a constant ventilation rate of 1,8 liter/sek. per m² gross floor area. The power needed for air transportation, SEL is 1,8 kJ/m³. There is no heat recovery. The ventilation also operates at night in hot summer periods. The airing windows are automatically controlled with the possibility to open during operation hours. There is mechanical exhaust from the toilets without heat recovery.

The lighting level is 200 lux in the offices and 50 lux in other rooms. The installed power is 12 W per m² gross floor area in the offices and 10 W per m² in other rooms. The lighting is on during operation hours. The lighting in the stairway is always on. In night there are light in the stairway and in the escalator plus in selected fixtures in the stairway room and in the core zone of the offices.

The office building is connected to the district heating network and heated by radiators. There are vertical distribution pipes for heating and hot water to both sides of the stairway. There is circulation on the hot water. Pipes and fittings are insulated with 10 mm insulation.

Office building 1980

The office building from 1980 has basically the same design and type of installations as the office building from 1960 and as the new office building. But the energy efficiency of the constructions and installations are different.

The flat roof is with 100 mm insulation and felt on top of the concrete slaps. The windows are with double glazing. The lower wall below the windows is with 95 mm insulation.The gable walls are with 100 - 150 mm concrete inner wall, 80 mm cavity with insulation and a ½ stone brick in the external façade. The basement slap is 185 mm hollow core concrete with flooring on top. There is no insulation in the gable walls or in the basement slap. The load baring partition walls are made of concrete elements. The rest of the partition walls are made of gypsum plates.

There are automatic controlled external solar shading with a solar reduction factor of 0,20 in front of all windows.

At the starting point there are balanced mechanical ventilation with heat recovery in the offices at a constant ventilation rate of 1,8 liter/sek. per m² gross floor area. The heat recovery efficiency is 0,60 and the power needed for air transportation, SEL is 2,5 kJ/m³. The ventilation also operates at night in hot summer periods. The airing windows are automatically controlled with the possibility to open during operation hours. There is mechanical exhaust from the toilets without heat recovery.

The lighting level is 200 lux in the offices and 50 lux in other rooms. The installed power is 10 W per m² gross floor area in the offices and 8 W per m² in other rooms. The lighting fixtures are manually controlled in three rows from the façade. The lighting in the stairway is always on. In night there are light in the stairway and in the escalator plus in selected fixtures in the stairway room and in the core zone of the offices.

The office building is connected to the district heating network and heated by radiators. There are vertical distribution pipes for heating and hot water to both sides of the stairway. There is circulation on the hot water. Pipes and fittings are insulated with 20 mm insulation.

The purpose of the report is to analyse the cost optimality of the energy requirements in the Danish Building Regulations 2010, BR10 to new building and to existing buildings undergoing major renovation.

The energy requirements in the Danish Building Regulations have by tradition always been based on the cost and benefits related to the private economical or financial perspective. Macro economical calculations have in the past only been made in addition. The cost optimum used in this report is thus based on the financial perspective. Due to the high energy taxes in Denmark there is a significant difference between the consumer price and the macro economical for energy.

The evaluation is performed by the Danish Building Research Institute on request from the Danish Energy Agency

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