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

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Content

Introduction

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 Transportation, Building and Housing Agency.

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 2018, BR18 introduced 1. January 2018. BR18 can be read at www.bygningsreglementet.dk in Danish. BR18 and BR 15 has the same energy requirements, But BR18 are just significantly restructured.

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:

- Energy requirements to new buildings 2015 – Economical Analyses (SBi 2016:13)
- Heating savings in the existing buildings – Potential and economic (SBi 2017:16)

The effort has focus on the Danish needs and the publications above are in Danish.

This report on the cost optimality of the energy requirements in the Danish Building Regulations is an update of the report published in 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 2018, BR18 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 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 2018 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 2018, BR18. The gap is in % of the cost optimum level of requirements in kWh/m^2 ann. primary energy inclusive and exclusive of renewables where relevant. Negative gap indicates the requirements in the Danish BR 18 being tighter than the cost optimum. BR 18 is the present minimum requirements in the Danish BR 18. B2020 is Building 2020 - the in BR 18 defined voluntary requirement for the future. Only the relevant heat supply sources in relation to the Danish heat plan act is included. For the office building the use of PV can influence the cost optimal point. If solutions both without and with PV is included in the energy packages calculated both are shown in the table. Solutions with PV are shown in italic. Fulfillment of Buildings 2020 in general requires use of PV.

Table 1. Cost optimality of the energy requirements to new buildings in the Danish Building Regulations 2018. 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 18	B2020
Single family house	District heating		58,7	- 30/- *40*	*- 56*
	Heat pump		46,1	- 28	*- 61*
Multifamily house	District heating		39,9	- 16/- *13*	*- 26*
Office building	District heating	Excl. PV	55,9	- 28/- *23*	*- 40*
		Incl. PV	36,2	11/ *18*	*- 8*
Weighted average	DK mix			- 21	*- 43*

Requirements to existing buildings undergoing major renovation

Table 2 summarises the cost optimality of the energy requirements in Renovation Class 2 and Renovation Class 1 in the Danish Building Regulations 2018 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. Fulfillment of Renovation Class 1 in general requires use of PV.

Table 2. Cost optimality of the energy requirements in the Danish Building Regulations 2018 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.	Class 2	Class 1
Single family, 1930	District heating		126,2	5	- *58*
	Natural gas		146,3	4	- *46*
	Heat pump		111,4	10	- *49*
Single family, 1960	District heating		117,7	10	- *51*
	Natural gas		132,1	10	- 48
	Heat pump		93,6	20	- *39*
Multifamily, 1930	District heating		55,3	*89*	- *9*
Multifamily, 1960	District heating	Excl. PV	60,2	48	- *17*
		Incl. PV	58,5	52	- *15*
Office building, 1960	District heating	Excl. PV	66,2	46	- *7*
		Incl. PV	58,8	65	*5*
Office building, 1980	District heating	Excl. PV	67,7	15	- *1*
		Incl. PV	60,3	29	*11*
Weighted average	DK mix			30	- 28

Primary energy demand

Table 3 summarises the primary energy demand 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 2018. The primary energy factor for the energy supply's is as today (2016). Solutions without PV are shown in normal text and solutions with PV are shown in italic.

Table 3. Primary energy demand 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 2018.

Building type	Heat supply	Primary energy in kWh/m^2 ann.	
		BR 18	B2020
Single family house	District heating	40,9/*35,5*	*25,9*
	Heat pump	33,5	*18,2*
Multifamily house	District heating	33,5/*34,7*	*30,1*
Office building	District heating	40,0/*42,7*	*33,4*

Table 4 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 2018 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, a little loft or roof insulation and improvement or replacement of installations.

Table 4. Primary energy demand 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 2018 to existing buildings undergoing major renovation.

Building type	Heat supply	Starting point	Primary energy in kWh/m^2 ann.	
		kWh/m^2 ann.	Class 2	Class 1
Single family house, 1930	District heating	269,1	131,9	*52,4*
	Natural gas	303,3	152,7	*78,3*
	Heat pump	265,9	122,4	*56,7*
Single family house, 1960	District heating	165,5	129,2	*57,9*
	Natural gas	184,2	144,7	69,2
	Heat pump	141,4	112,4	*57,0*
Multifamily house, 1930	District heating	142,9	*104,4*	*50,1*
Multifamily house, 1960	District heating	109,8	89,2	*49,7*
Office building, 1960	District heating	128,4	96,7	*61,6*
Office building, 1980	District heating	108,1	77,8	*66,8*

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 - 117 %. 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 25 % to an excessive tightness of 33 % for the buildings complying with the 2018 requirement. For the new buildings complying with the Building 2020 requirement the individual building elements in the envelope are in the range from a gap of 25 % to an excessive tightness of 43 %

Component requirements to existing buildings undergoing renovation

In relation to component requirements to building envelope elements undergoing renovation the difference to cost optimality for the individual building elements in the envelope are in the range from a gap of 50 % to an excessive tightness of 23 %. The larges gap relates to insulation of parallel roof and whether the additional construction height is cost efficient.

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 in the small building, but are cost efficient in the larger building with a large solar exposed roof and a significant electricity consumption measured by one meter e.g. in medium size office buildings and in large residential with common ned of power for light and mechanical ventilation.

Conclusions

New buildings
In relation to the new housing examples the present minimum energy requirements in BR 18 all shows gaps that are negative with a deviation of up till 30 % from the point of cost optimality if PV is not part of the energy solution and uptill 40 % if PV is part of the solution. In relation to Buildings 2020 the negative gap increases up till maximal 56 %. PV is in all examples needed to fulfill the Buildings 2020 requirement.

In relation to the new office building there is a gap of 11 or 18 % to the point of cost optimality in relation to the 2018 requirement if the cost optimal point is calculated inclusive of PV. In relation to the Buildings 2020 requirement there are negative gaps to the point of cost optimality of 8 % if the cost optimal point is calculated inclusive of PV and 40 % if the cost optimal point is calculated exclusive of PV.

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 negative gap of - 21 % in average for the new building fulfillling the energy requirements in BR18. The negative gap increases to - 43 % in relation to the Building 2020 energy requirements.

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 can if there is a large solar exposed roof be cost beneficial in some buildings today. This creates new possibility for cost efficiency, but also a significant unsertanty in setting general cost efficiency energy requirements to be used for all building independent of size and solar exposior.

Existing buildings

Component requirements

The component requirements are in average close to the point of cost optimal. But deviations occurs for some components. It could be considered to tighten the requirement to insulation in the cases of major deviation e.g. the case of parallel roofs.

Major renovation

In relation to the requirements in Renovation Class 2 to major renovation the gap between requirements and cost optimality are in general too large. The requirements has to be tightened at least with the focus on large buildings.

The requirements in Renovation Class 1 are past the point of cost optimal.

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.

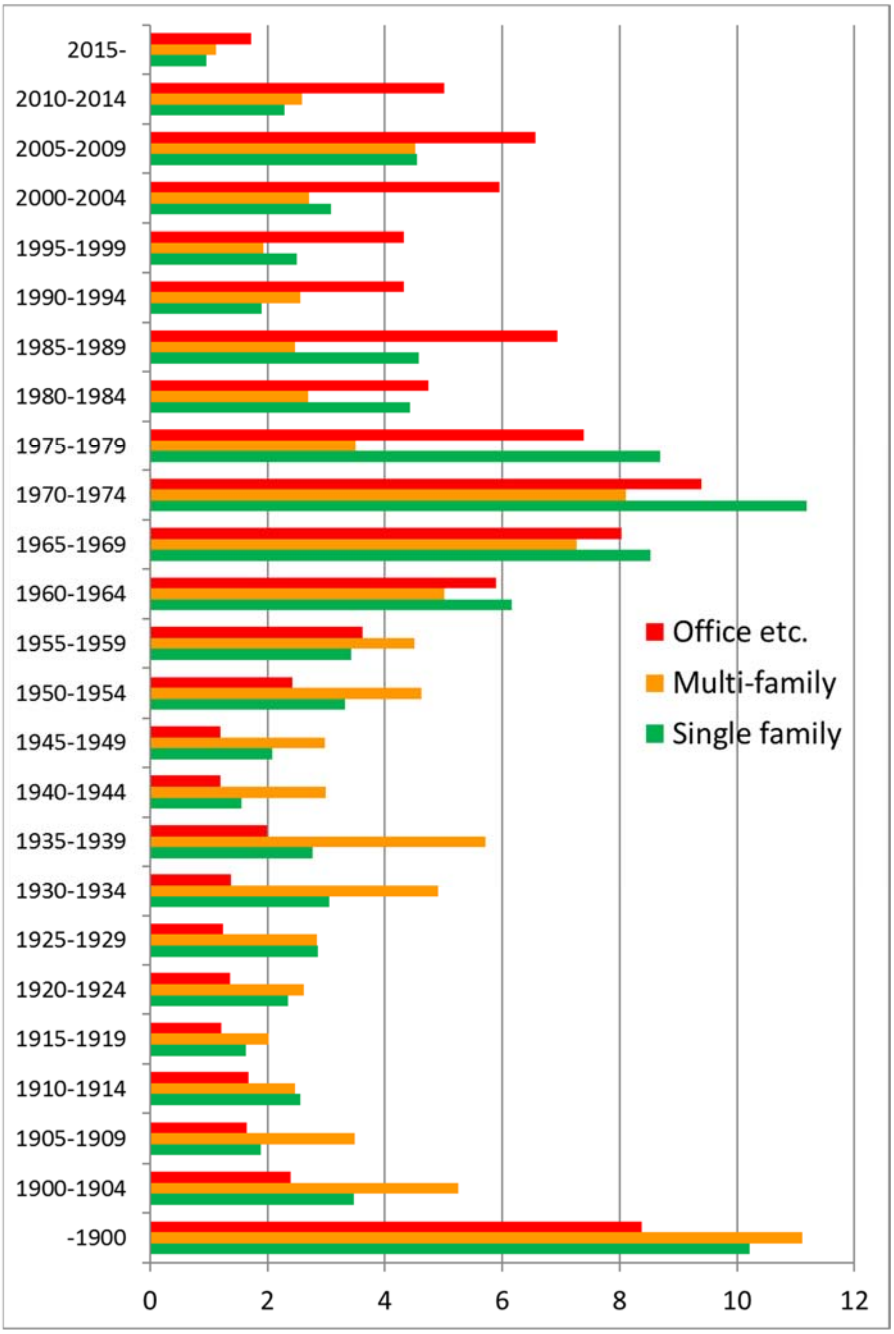
Gross floor area of different building types in the Danish building stock. Last year included are buildings constructed in 2017.

Building type	Gross floor area in 1.000 m^2:	- 2009	2010 -
Farm houses		21.457	462
Detached single family houses		158.022	4.850
Row houses		35.525	1.884
Apartment blocks		83.869	2.710
Student residence		1.415	98
Residential home		4.240	632
Other housing		551	36
Administrative and commercial buildings etc.		57.436	4.826
Hotel, restaurant etc.		6.340	360
Transport and commerce etc.		732	47
Museum, church, library etc.		4.887	233
Education and research etc.		21.895	1.095
Hospitals etc..		4.398	384
Day-care institutions		3.341	242
Other institutions		1.237	50
Total		405.345	17.909

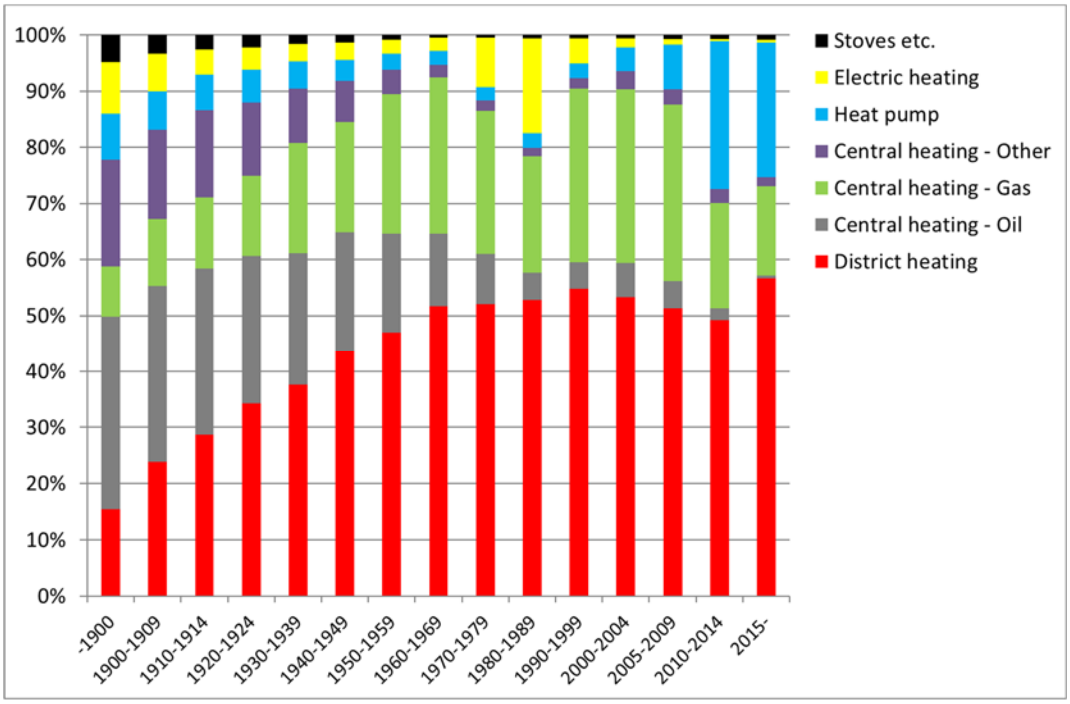
In the statistics for the Danish building stock in this section of the report the term Single family houses includes Farm houses, Detached single family houses and Row houses. Multifamily houses includes Apartment blocks, Student residence, Residential home and Other housing. The term Office buildings 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

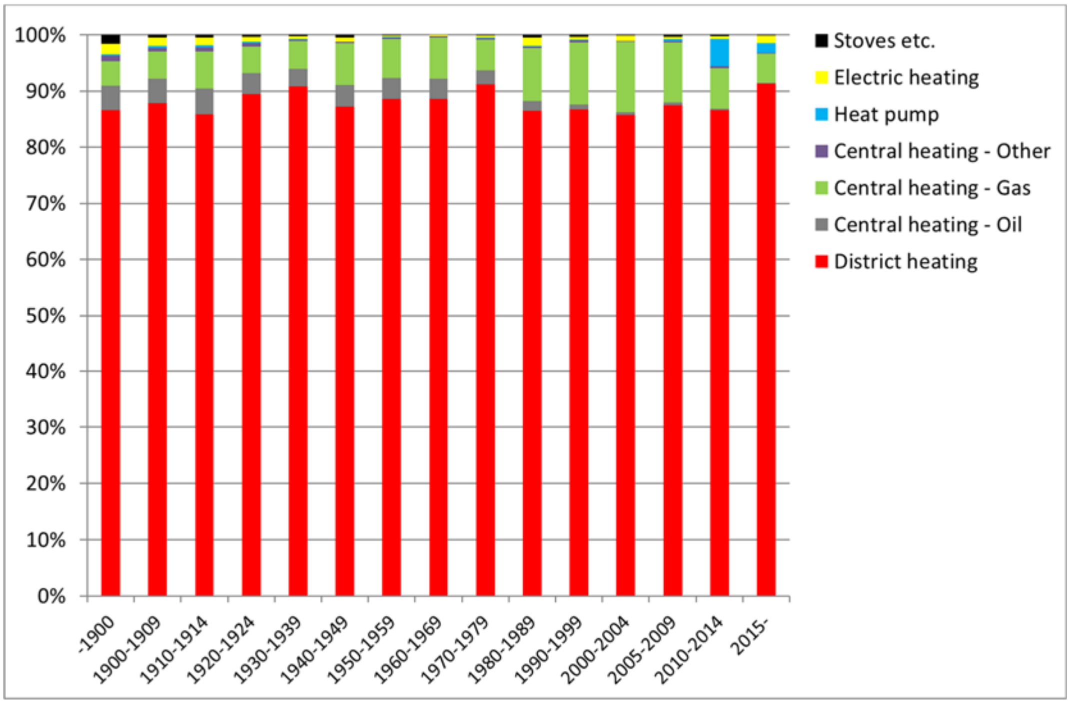
Building type	No. buildings	No. dwellings	Gross floor area, 1000 m^2
Single family houses	1.465.720	1.635.676	222.236
Multifamily houses	103.347	1.157.916	93.610
Office buildings etc.	139.490	-	107.569
Total	1.708.557	2.793.592	423.415



Construction year for the Danish building stock for each of the three lump building types: Single family houses, Multi family houses and Offices. The percentage is per each of the three lump building types.



Heating supply in existing single family houses inclusiv of recently constructed single family houses.

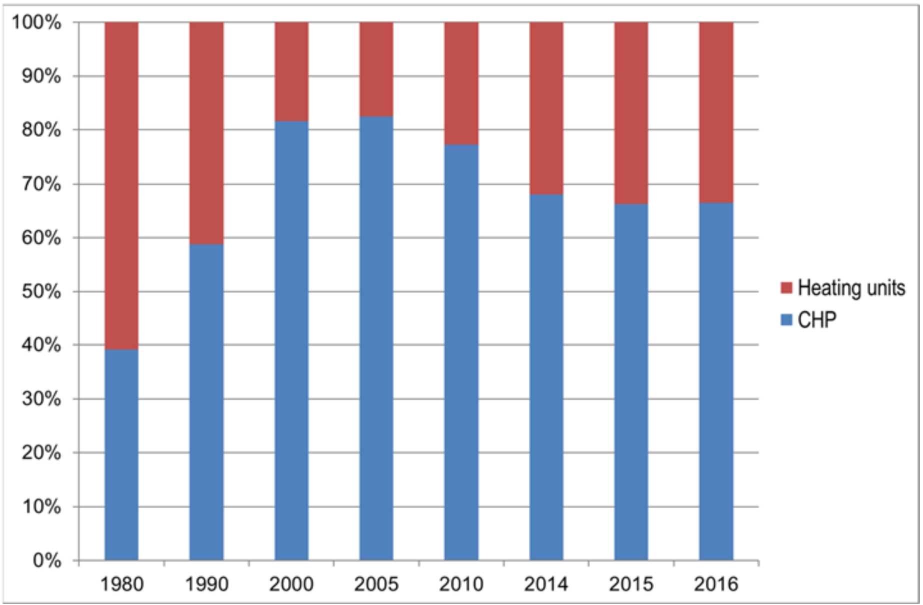


Heating supply in existing multifamily houses inclusive of recently constructed multifamily houses.

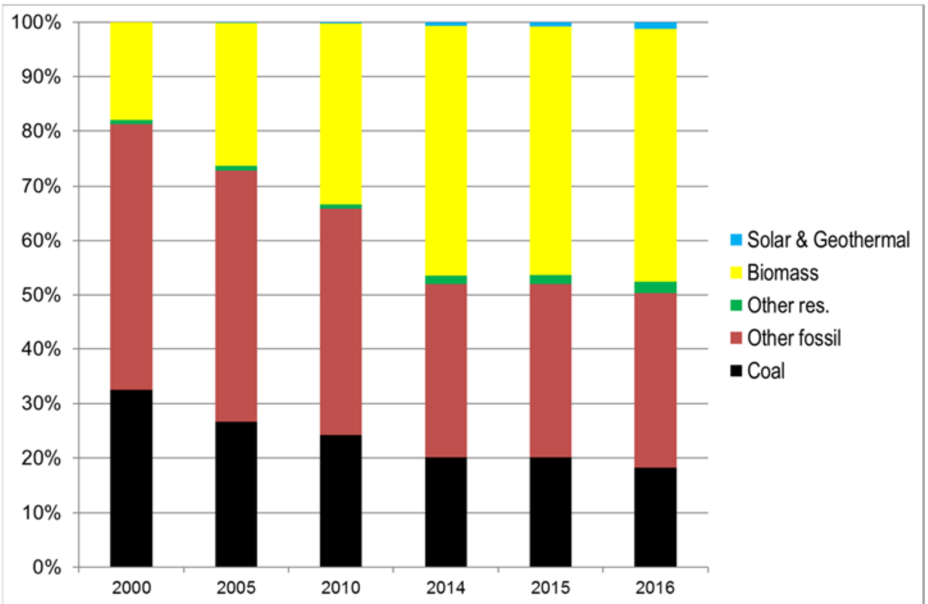
Danish energy supply

The general Danish energy policy is briefly described in: "Denmark's Energy and Climate Outlook 2017" published by the Danish Energy Agency in March 2017.

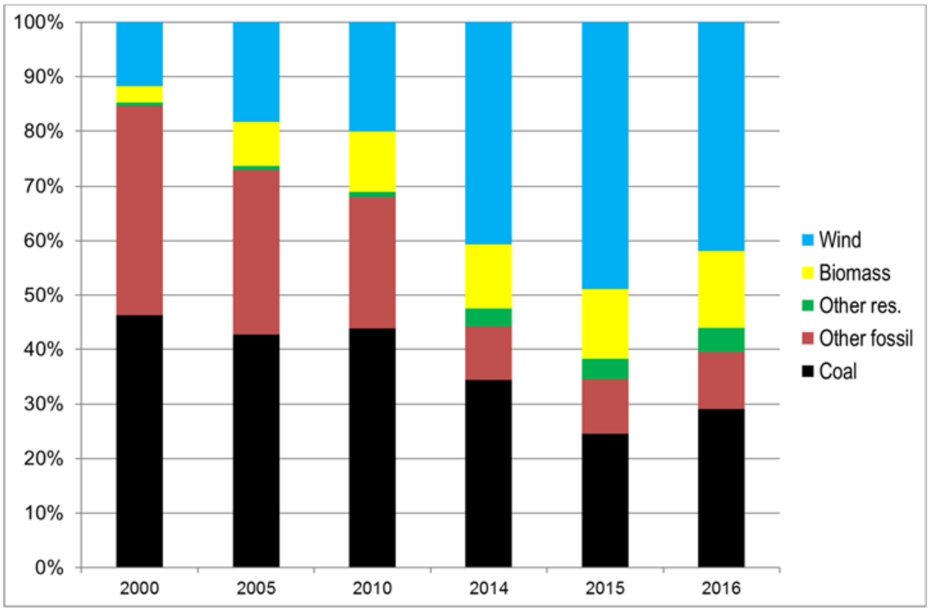
The information on the present Danish energy supply system in this chapter is based on data from the Danish Energy Statistics 2016.



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

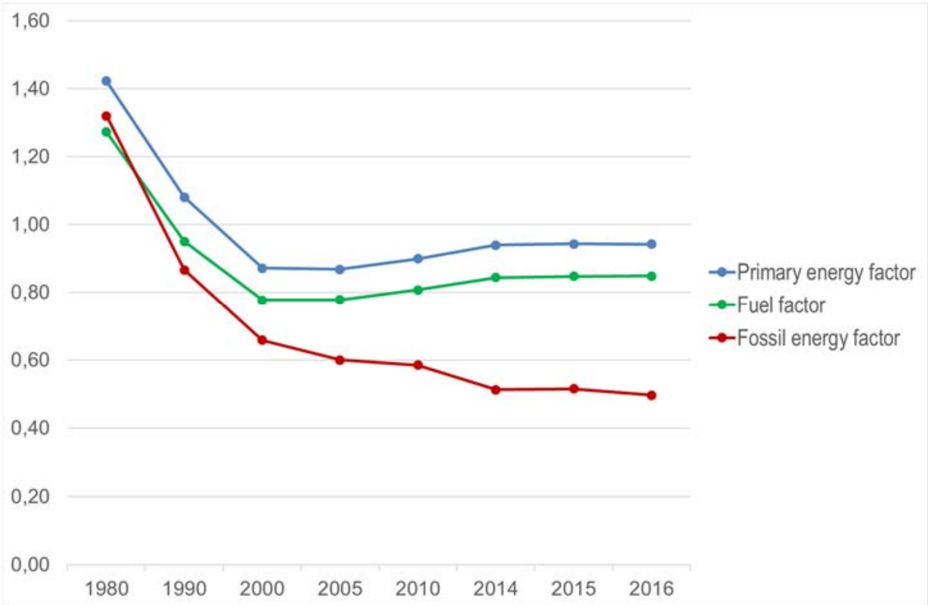
Extraction is not included in the Danish energy statistics except for natural gas produced in the Danish area of the North Sea.

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.

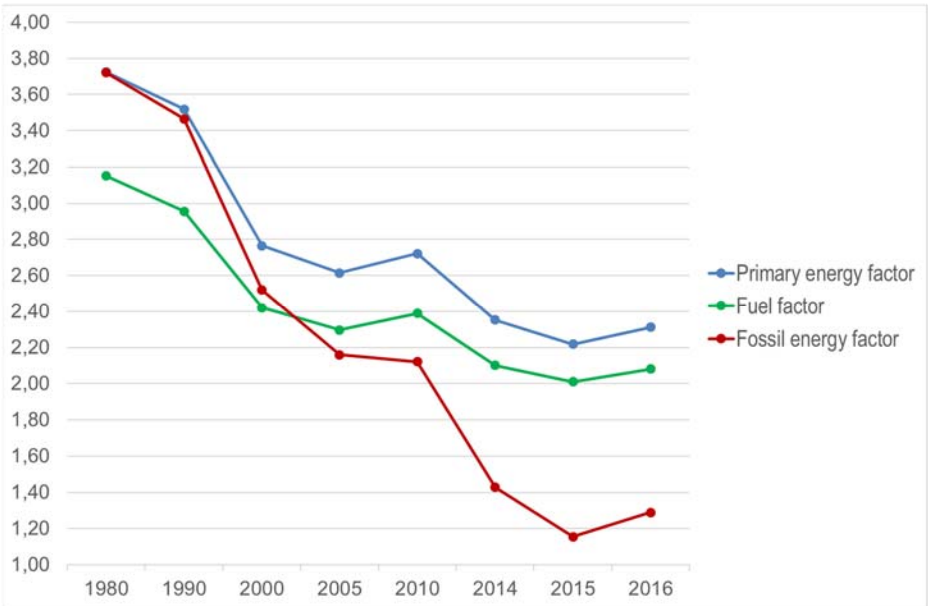
A heating efficiency of 200 % is used to calculate the energy need for heating in relation to CHP production in district heating and power supply systems. The 200 % efficiency is close to the figures calculated for the systems using more detailed exergy calculations.

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. 2016.

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	0,94	0,85	0,50	104
Electricity	2,31	2,08	1,29	329



Development in total primary energy factor and fossil energy factor for district heating over the past years.



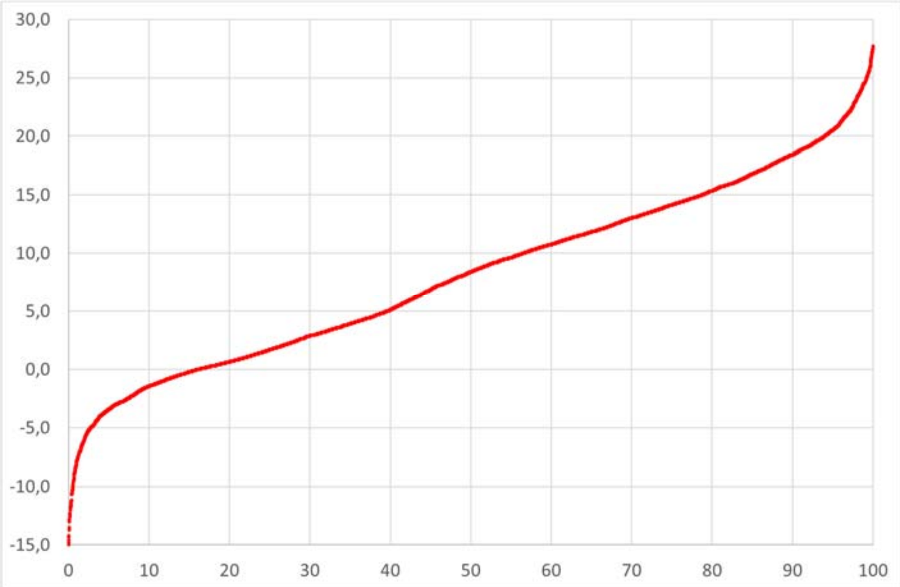
Development in total primary energy factor and fossil energy factor for electricity over the past years.

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/m^2
January	0,7	- 1,3	2,3	13
February	0,4	- 1,2	2,0	31
March	- 0,7	- 4,1	2,3	73
April	7,1	3,5	10,8	123
May	11,5	7,3	15,4	159
June	14,2	9,5	18,2	159
July	17,8	12,5	22,3	158
August	17,9	13,5	22,2	139
September	14,5	10,9	18,0	94
October	9,8	7,0	12,1	50
November	3,4	1,5	5,1	17
December	0,7	- 1,3	2,2	10
Year	8,1			1.026



External temperature in the Danish design reference year, 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

Building regulations 2015, BR 15 was in force until 1. January 2018 where a new Building Regulations 2018, BR 18 was put into force. There is a half year transition period until 1. July 2018, where BR 15 can still be used for building permit requests, if the building owner decides so. The requirements in the two regulations are the same. But the editorial structure, the numbering and the administrative provisions are significant different in the new BR 18 regulations. For the rest of the report reference will only be made to BR18.

The relevant sections of the Danish Building Regulations 2018, BR 18 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:
- Energy consumption
- Energy performance frameworks in new buildings
- Change of use and extensions

Energy requirements to existing building undergoing renovation:
- Energy consumption
- Energy performance frameworks in existing buildings
- Change of use and extensions
- 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:
- Indoor climate
- Ventilation
- Light conditions

- Energy consumption
- General
- Minimum thermal insulation

- Services
- General
- Distribution systems for heating, cooling and domestic hot water
- Ventilation systems
- Combustion plants and exhaust systems
- Solar heating systems, solar photovoltaic arrays, cooling systems and heat pumps.

The core energy requirements in BR18 to new building and to existing buildings undergoing renovation are summarised on the following pages.

There are also energy requirement in BR18 to holiday homes and temporary portable cabins. These types of building are not included in the Delegated Regulations and are exemted from the EPBD, 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 (30 + 1000/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.

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 (41 + 1000/A) kWh/m²/year, where A is the heated floor area.

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. This is a flexabel method to address different building types and conditions. Process energy such as ventilation of fume cabinets is not included in the energy performance framework.

Buildings heated to more than 5°C and up to 15°C must fulfil the same energy performance framework as office buildings. 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, internal heat gains 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. Verification must be on the basis of SBi Guidelines 213, “Bygningers energibehov” [Energy demands of buildings].

Buildings must be built such that the design transmission loss does not exceed 4 W per m² of the building envelope in the case of single-storey buildings, 5 W for two-storey buildings and 6 W for buildings with three storeys or more. The calculation does not include the area of windows and doors nor the transmission loss through them.

Insulation of individual building elements in the building envelope must be at least on a par with the values stated in table on next page

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.

Air changes through leakage in the building envelope must not exceed 1.0 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 ISO 9972, Thermal performance of buildings – Determination of air permeability of buildings –Fan pressurisation method.

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

Building 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.

Offices, schools, institutions and other buildings not covered above 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.

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.

Air changes through leakage in the envelope in class 2020 buildings must not exceed 0.5 l/s/m² of the heated floor area when tested at a pressure of 50 Pa.

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.

Energy requirements to extensions to buildings

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 small 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.

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

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

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 on next page. For windows, doors, hatches, roof lights and skylight domes, the U-values for the actual size apply.

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.

In the case of a change of use, constructional conditions 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.

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.

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 specific requirements were satisfied.

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

Energy requirements to existing buildings undergoing renovation

The energy requirements to existing buildings undergoing renovation are either to the building as such or to the individual building elements.

Energy frame for existing buildings

As an alternative to the component requirements for existing buildings, the requirements for conversion may be met through compliance with the energy performance frameworks for existing buildings.

Dwellings, student accommodation, hotels, etc. may be classified as renovation class 2 when the total demand for energy supply for heating, ventilation, cooling and domestic hot water per m² of heated floor area does not exceed (110 + 3200/A)kWh/m² per year, where A is the heated floor area.

Dwellings, student accommodation, hotels, etc. may be classified as renovation class 1 when the total demand for energy supply for heating, ventilation, cooling and domestic hot water per m² of heated floor area does not exceed (52.5 + 1650/A)kWh/m² per year, where A is the heated floor area.

Offices, schools, institutions, etc. may be classified as renovation class 2 when the total demand for energy supply for heating, ventilation, cooling, domestic hot water and lighting per m² of heated floor area does not exceed (135 + 3200/A)kWh/m² per year, where A is the heated floor area.

Offices, schools, institutions, etc. may be classified as renovation class 1 when the total demand for energy supply for heating, ventilation, cooling, domestic hot water and lighting per m² of heated floor area does not exceed (71.3 + 1650/A)kWh/m² per year, where A is the heated floor area.

To use the renovation classes, the requirement for supplied energy must be improved by at least 30 kWh/m² as at year.

Component requirements

Buildings elements are both construction elements and windows in the building envelope and installation elements e.g. ventilation system, boiler or heat pump.

For the construction elements in the envelope of existing buildings the regulation distinguishes 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.

In 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.

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

Cost-effective energy savings

A separate guideline to BR18 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. A table in BR18 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.

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 the table on next page. Provisions which are expected to be introduced in 2020 are also given in the table.

The energy gain is calculated as stated in BR18. The requirement applies to a CEN 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.

Requirements to energy gain through windows and rooflights in kWh/m²/year.

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

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. 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.

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.

Circulating pumps in heating, hot water, geothermal heating and cooling systems must comply with EcoDesign.

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.

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. The requirement to insulation in DS 452 is in general tight compared to requirements or praxis elsewhere.

Ventilation

Single-family houses may be ventilated by natural or mechanical ventilation.

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.

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.

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.

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 1.000 ppm. 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.

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 CO_2 content in the indoor air must not exceed 1.000 ppm. for extended periods. If a ventilation system with demand-controlled ventilation is used, the specified air volumes may deviate 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.

Ventilation units must comply with EcoDesign. Ventilation installations that supply one dwelling must incorporate heat recovery with a temperature efficiency of no less than 80%.

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.

For ventilation installations with a constant or variable air volume and heat recovery supplying one 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.

Equipment for humidifying intake air may only be installed if this is warranted by reasons of safety, production, preservation or health.

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.

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 BR 18. 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	2015	2020
District heating	0,8	0,6
Other heating	1,0	1,0
Electricity	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 up till a primary energy surplus limit of 25 kWh/m2 ann.

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 BR18. 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 the European EPB standards from 2008. 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.

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.

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. 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. It is the same reference buildings as was used in the previous Danish Cost Optimal analysis in 2013.

The rule in BR18 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 BR18 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, a little additional insulation on loft's and improvement or replacement of installations e.g. boilers, heat pumps, ventilation and lighting systems to present standard.

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

Summary of the new reference buildings.

Building type	Heat supply	Gross floor area m2	Storey No.
Single family house	District heating Heat pump	150	1
Multifamily house	District heating	1080	3
Office building	District heating	3283	4

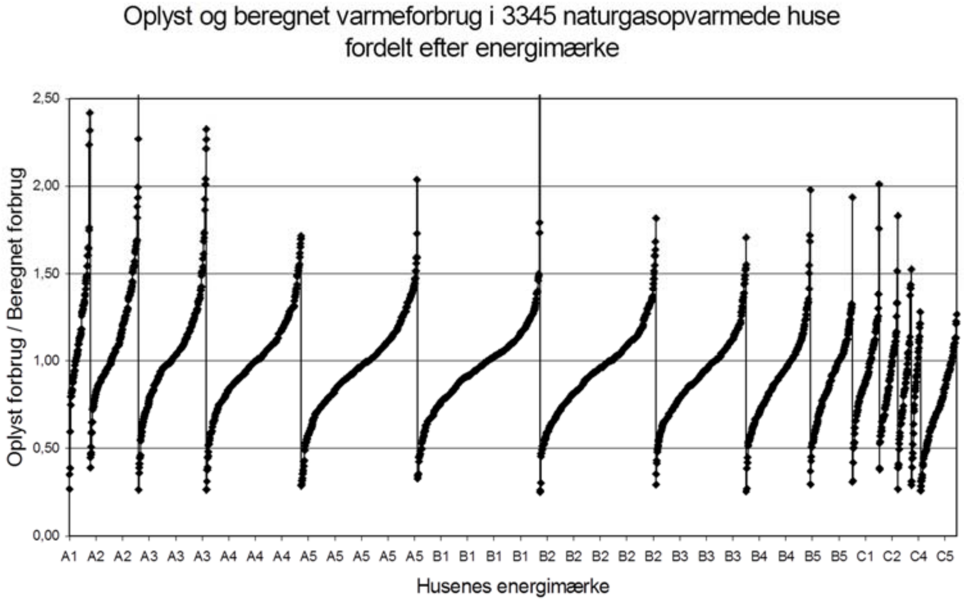
Summary of the reference buildings for existing buildings.

Building type	Heat supply	Gross floor area m2	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.

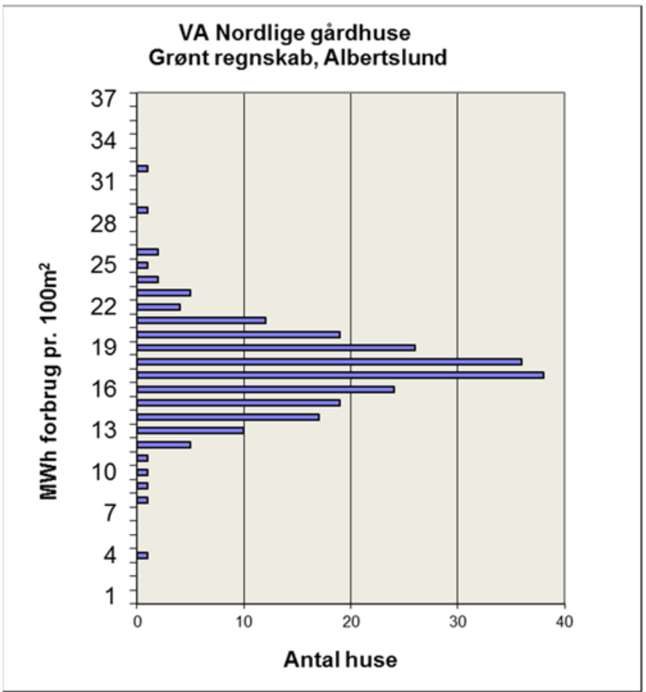
In the evaluation of the cost-optimal level of the energy requirements to new buildings in BR18 an internal temperature of 20 C is used. It compensates both the higher external temperature in relation to the different in external temperature between last years and DRY and the higher room temperature 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.



Costs

All costs are in 2017 prices.

Discount rate

The Danish national debt in each of the years 2013-2017 has an interest rate of 0,0 % p.a. 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 2017 price level in relation to the macro-economic 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 safer 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.

As an alternative to the discount rate required in the Delegated Regulations Denmark also use an alternative discount rate of 4,0 % p.a. in the sensitivity analysis to reflex the rate normally used in Denmark for this type of calculations.

The housing mortgage interest rate was for the period 1998-2017 in average 2,5 % p.a. and the commercial mortgage interest rate was for the same period in average 2,7 % p.a. The mortgage interest rate is subtracted in the taxation by 30 % in average for private persons e.g. in housing and by 22 % for commercial business. The inflation rate for the same period was 1,8 % p.a. The resulting net interest rate for the period 1998-2017 was then 0,7 % p.a. for private housing and 1,0 % p.a. for commercial. These rates are used in the calculations. In the sensitivity analysis an alternative interest rate of 3,0 % p.a. is used

Mortgage and inflation are from Danish Statistics and from "Assumptions for socio-economic analyses in the energy sector - Tables September 2017" 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 2017" by the Danish Energy Agency. The tables include projections for each of the years 2017 - 2040. 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 2017. 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.

The prices don't include the cost for the future development of the energy supply system in relation to carbon neutrality. The energy prices in the period inclusive of 2017 used in this report is lower than the energy prices in the previous Danish report on cost optimality from 2013.

Natural gas

Macroeconomic

Gas price 2017:	174 DKK/MWh
Price increase the coming years:	2.7 % p.a.

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

Financial

Gas price, 2017:	514 DKK/MWh
Price increase the coming years:	1.3 % 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. In some cases, subscription relates to needed max. power or consumption the past years.

Macroeconomic

District Heating price 2017:	198 DKK/MWh
Price increase the coming years:	2.8 % p.a.

Figures from Varmepriser VEKS 2017 !.

Financial

District heating price, 2017:	391 DKK/MWh
Price increase the coming years:	1.9 % p.a.

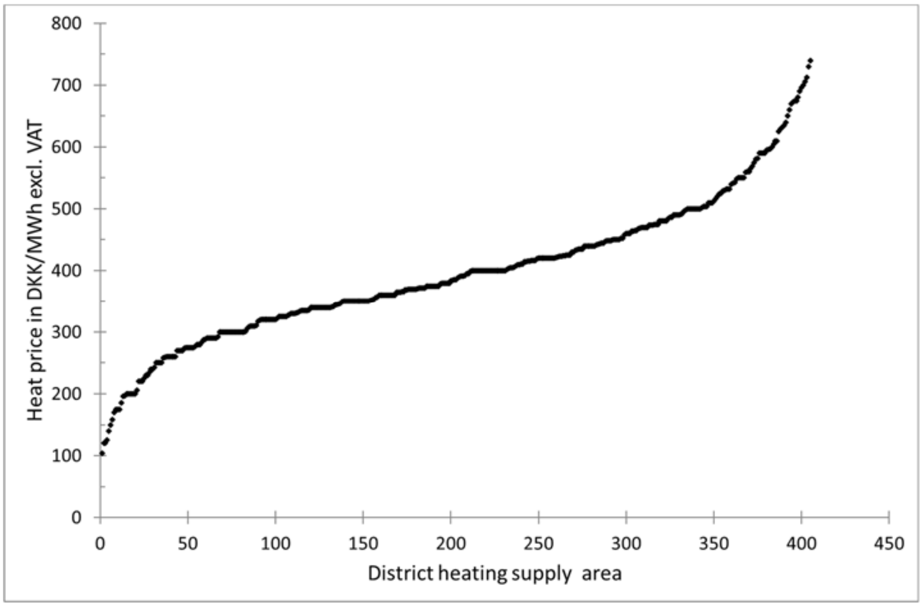
The variation in the district heating price for different supply areas is large, see figure on next page. The variation in the district heating price for different consumers in the same supply areas is limited.

Electricity

Macroeconomic

Electricity price, private household, 2017:	516 DKK/MWh
Price increase the coming years:	1.8 % p.a.
Electricity price, commercial, 2017:	394 DKK/MWh
Price increase the coming years:	2.2 % p.a.

Figures from Assumptions for socio-economic analyses, Table 7



Variation in the district heating price for different supply areas.

Financial

Electricity price, private household, 2017:	1,800 DKK/MWh
Price increase the coming years:	0.8 % p.a.
Electricity price, private house, electric heating, 2017:	1,295 DKK/MWh
Price increase the coming years:	1.0 % p.a.
Electricity price, commercial, 2017:	1,640 DKK/MWh
Price increase the coming years:	0.8 % p.a.

CO_2 emission

The CO_2 emissions trend are extracted from: "Assumptions for socio-economic analyses in the energy sector - Tables September 2017" 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: 0.0 % p.a.

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

District Heating

Decrease in CO_2 emission the coming years: 0.0 % p.a.

Figures from Assumptions for socio-economic analyses, Table 10.

Electricity

Decrease in CO_2 emission the coming years: 0.0 % p.a.

Figures from Assumptions for socio-economic analyses, Table 10.

The figures on CO_2 emission the coming years reflex that the assumptions by the Danish Energy Agency only includes politically decided future development of the Energy Supply System and the fact that there is yet no political decision on the further improvement of the Energy Supply System in relation to Carbon reduction. Political decisions on this is expected in the first half of 2018.

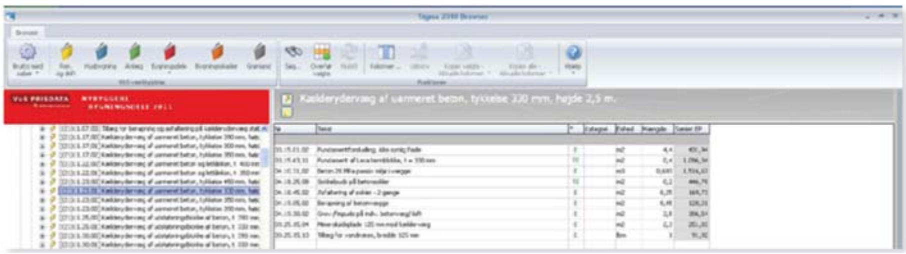
CO_2 emission costs

The CO_2 emissions cost and trend in costs are extracted from: "Assumptions for socio-economic analyses in the energy sector - Tables September 2017" 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.

CO_2 emission costs, 2017:	150 DKK/ton-CO_2
Increase in CO_2 emission costs the coming years:	5.7 % p.a.

Construction and renovation costs

Construction and renovation costs are in general from Molio Price Data (former V&S Price Data) if other sources are not mentioned. The Molio Price Data is operated by Molio (former 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. Prices for different sizes of work can be extracted directly in the database. The prices in Molio Price Data are exclusive of VAT. Prices are updated annual.



The Molio 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

The price databases are divided in section. In the case of 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

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	120 + 45	0,213	125	0,229	100	0,179
1	120 + 70	0,186	150	0,200	150	0,145
2	120 + 95	0,165	190	0,163	200	0,122
3	120 +120	0,149	250	0,131	300	0,092
4	120 +145	0,135	300	0,112	350	0,082
5	120 +170	0,124			425	0,071
6	120 +195	0,114				
7	120 +220	0,106				
8	120 +245	0,099				

Foundation

There are three variations of constructing the upper part of the foundation. Version C includes one light concrete block with insulation on top of a standard light concrete block. Version B includes two light concrete block with insulation on top of each other. Version A includes two light concrete block with insulation on top of a standard light concrete block. The linear thermal loss depends on both the type of foundation, on the thickness of the foundation which again depend on the thickness of the wall and the thickness of the insulation and on the insulation of the slap.

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.

Water to water heat pump

The prices available are based on heat pumps tested at 0/35 C. The figures in brackets in the table are for the normal test temperature set of 0/35. In accordance with DS469 a water 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 water to water heat pump at test temperatures should be at least 50 % 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 water to water heat pump has a COP at test temperatures of 4,24. The heat pump is with on-off control. The relative COP at 50 % part load is 0,99 for the actually used 10 kW heat pump.

Windows

Windows are energy class B and A in accordance with the requirements in BR 18 for 2018 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 basic 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 is 0,10 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV

The solar cell, PV system has a peak power of 165 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 10^o. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 (m^2)	Maintenance DKK/unit (m^2)	Life time years
District heating unit and connection		All	45.654	1.783	30
Heat pump		6 (5,3) kW	111.044	4.442	20
Water to water		8 (7,5)	121.230	4.849	
Incl. pipes in ground		10 (9,4)	135.374	5.415	
		12 (11,0)	148.535	5.941	
Loft		120 + 45 mm	744	0	50
		120 + 70	752		
		120 + 95	758		
		120 +120	780		
		120 +145	798		
		120 +170	823		
		120 +195	835		
		120 +220	861		
		120 +245	879		
Wall		125 mm	2.018	0	80
		150	2.051		
		190	2.085		
		250	2.137		
		300	2.225		
Slap		100 mm	537	0	80
		150	571		
		200	605		
		300	674		
		350	720		
		425	772		
Foundations type C		125 mm	1.319	0	80
		150	1.391		
		190	1.476		
		250	1.574		
Foundations type B		125 mm	1.353	0	80
		150	1.415		
		190	1.483		
		250	1.692		
		300	1.763		
Foundations type A		125 mm	1.538	0	80
		150	1.619		
		190	1.708		
		250	2.166		
		300	2.256		
Windows		B	3.187	0	30
		A	3.916		
Ventilation		Natural	9.000	450	30
		Mechanical	43.881	1.519	
PV	1:	1,40 kWp	18.100 + 5.000	2 % p.a.	20 (10)
+ inverter	2:	2,20	25.640 + 7.400		
	3:	3,00	33.180 + 7.400		
	4:	4,30	43.680 +10.800		
	6:	6,00	57.160 +13.200		

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, improvement of the foundation, 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.

The figures in bold are the cost optimal point. In the table the single wave line indicates the minimum insulation package needed to fulfil the minimum requirement to the building envelope in BR18. The single underline indicates the minimum solution to fulfil the energy frame requirement in BR18. There are two solutions to this in the table, one not using PV and one using PV to fulfil the energy frame requirement. The bold wave underline and the double underline indicates the same for the future Building 2020 requirement.

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

Code	Loft	Wall	Slap	Found.	Win.	Vent.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Type	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SFN.DH.000C.B.NV.No	165	125	100	C	B	NV	No	76,85	4.402	5.498
SFN.DH.100C.B.NV.No	190	125	100	C	B	NV	No	74,66	4.394	5.463
SFN.DH.200C.B.NV.No	215	125	100	C	B	NV	No	72,95	4.387	5.436
SFN.DH.300C.B.NV.No	240	125	100	C	B	NV	No	71,64	4.396	5.429
SFN.DH.400C.B.NV.No	265	125	100	C	B	NV	No	70,51	4.404	5.423
SFN.DH.500C.B.NV.No	290	125	100	C	B	NV	No	69,63	4.418	5.428
SFN.DH.401C.B.NV.No	265	125	150	C	B	NV	No	67,49	4.404	5.384
SFN.DH.402C.B.NV.No	265	125	200	C	B	NV	No	65,79	4.414	5.370
SFN.DH.403C.B.NV.No	265	125	300	C	B	NV	No	63,59	4.443	5.364
SFN.DH.404C.B.NV.No	265	125	350	C	B	NV	No	62,83	4.467	5.374
SFN.DH.413C.B.NV.No	265	150	300	C	B	NV	No	61,83	4.468	5.362
SFN.DH.423C.B.NV.No	265	190	300	C	B	NV	No	59,25	4.492	5.348
SFN.DH.433C.B.NV.No	265	250	300	C	B	NV	No	57,43	4.534	5.359
SFN.DH.423B.B.NV.No	265	190	300	B	B	NV	No	58,74	4.490	5.340
SFN.DH.423A.B.NV.No	265	190	300	A	B	NV	No	58,31	4.547	5.381
SFN.DH.423B.B.MV.No	265	190	300	B	B	MV	No	51,22	4.848	5.821
SFN.DH.423B.A.NV.No	265	190	300	B	A	NV	No	53,12	4.612	5.434
SFN.DH.423B.B.NV.PV1	265	190	300	B	B	NV	PV1	45,56	4.719	5.532
SFN.DH.423B.B.NV.PV2	265	190	300	B	B	NV	PV2	38,02	4.807	5.618
SFN.DH.724B.B.NV.No	340	190	350	B	B	NV	No	55,85	4.552	5.362
SFN.DH.724B.B.MV.No	340	190	350	B	B	MV	No	48,63	4.911	5.850
SFN.DH.825A.A.MV.No	365	190	425	A	A	MV	No	40,89	5.127	5.989
SFN.DH.724B.B.MV.PV1	340	190	350	B	B	MV	PV1	35,45	5.141	6.046
SFN.DH.835A.A.MV.No	365	250	425	A	A	MV	No	39,06	5.265	6.080
SFN.DH.835A.A.MV.PV1	365	250	425	A	A	MV	PV1	25,88	5.495	6.272

For the single family house with district heating the energy frame requirement in the Danish Building Regulations 2018, BR18 is tighter than the point of cost optimality, showing a gap of -30 % for the solution without PV and a gap of - 40 % for the solution with PV. For Building 2020, where PV is needed to fulfill the requirement, the over-performance increases to a gap of - 56 %. The calculated over-performance is based on today's prices and solutions and could possibly be levelled out by future development in solutions, energy and construction costs.

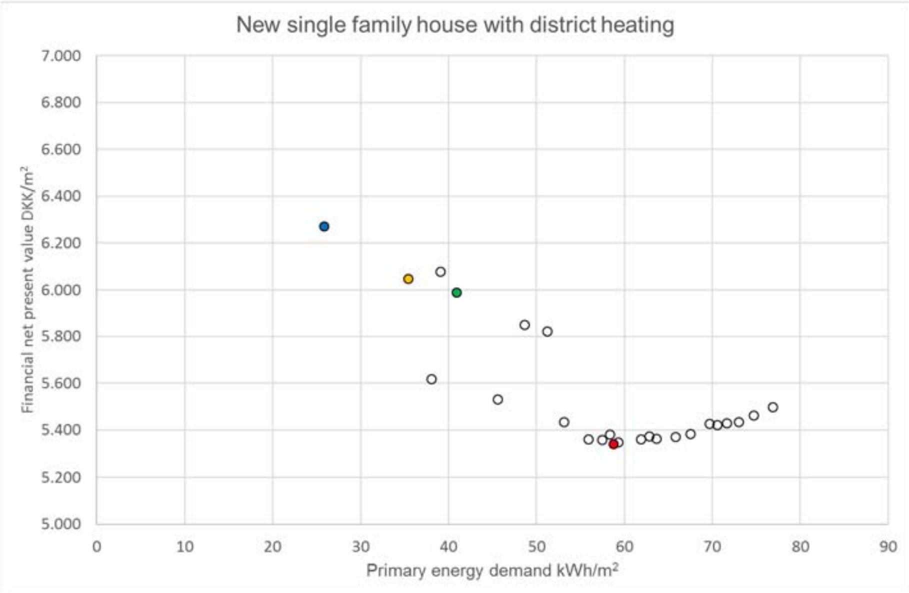
In the table below the same is shown for the new single family in the case of heating with a ground coupled heat pump.

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 2018, BR18 is closer to the point of cost optimality, showing a gap of - 28 % for a solution without PV. For Building 2020 where PV is needed to fulfill the requirement the over-performance increases to a gap of - 61 %.

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

Code	Loft	Wall	Slap	Found.	Win.	Vent.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Type	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SFN.HPG.000C.B.NV.No	165	125	100	C	B	NV	No	53,16	5.428	6.919
SFN.HPG.100C.B.NV.No	190	125	100	C	B	NV	No	51,76	5.425	6.895
SFN.HPG.200C.B.NV.No	215	125	100	C	B	NV	No	50,68	5.423	6.877
SFN.HPG.300C.B.NV.No	240	125	100	C	B	NV	No	49,87	5.436	6.877
SFN.HPG.400C.B.NV.No	265	125	100	C	B	NV	No	49,14	5.447	6.876
SFN.HPG.500C.B.NV.No	290	125	100	C	B	NV	No	48,59	5.464	6.885
SFN.HPG.401C.B.NV.No	265	125	150	C	B	NV	No	47,22	5.455	6.852
SFN.HPG.402C.B.NV.No	265	125	200	C	B	NV	No	46,11	5.470	6.845
SFN.HPG.403C.B.NV.No	265	125	300	C	B	NV	No	45,48	5.509	6.868
SFN.HPG.412C.B.NV.No	265	150	200	C	B	NV	No	45,03	5.500	6.853
SFN.HPG.402B.B.NV.No	265	125	200	B	B	NV	No	45,91	5.477	6.848
SFN.HPG.402C.B.MV.No	265	125	200	C	B	MV	No	42,90	5.860	7.345
SFN.HPG.402C.A.NV.No	265	125	200	C	A	NV	No	42,55	5.607	6.967
SFN.HPG.402C.B.NV.PV1	265	125	200	C	B	NV	PV1	32,93	5.699	7.138
SFN.HPG.724B.B.NV.No	340	190	350	B	B	NV	No	39,76	5.634	6.886
SFN.HPG.724B.B.MV.No	340	190	350	B	B	MV	No	37,08	6.028	7.398
SFN.HPG.724B.A.MV.No	340	190	350	B	A	MV	No	33,45	6.164	7.518
SFN.HPG.835A.A.MV.No	365	250	425	A	A	MV	No	31,20	6.409	7.687
SFN.HPG.835A.A.MV.PV1	365	250	425	A	A	MV	PV1	18,20	6.638	7.989

Finally the relation between primary energy demand and financial net present value is plotted for the heating supplies district heating. 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. Primary energy consumption and financial net present value. Red point is cost optimal. Green point is BR18 requirement without PV. Yellow point is BR18 requirement with PV. 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		Basement wall		Basement floor	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	120 + 45	0,213	125	0,251	100	0,277	100	0,158
1	120 + 70	0,186	150	0,212	125	0,234	150	0,131
2	120 + 95	0,165	190	0,170	150	0,203	200	0,112
3	120 +120	0,149	250	0,130	200	0,160	300	0,086
4	120 +145	0,135	300	0,109	250	0,132	350	0,077
5	120 +170	0,124					425	0,067
6	120 +195	0,114						
7	120 +220	0,106						
8	120 +245	0,099						

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.

Windows
Windows are energy class B and A in accordance with the requirements in BR 18 for 2018 and 2020.

Standard mechanical ventilation
The standard mechanical ventilation is demand controlled and has an basic mechanical air exchange rate of 0,30 l/s per m^2 gross floor area. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^{o}C. The specific power for air transportation, SEL is 1,50 kJ/m^3 at average load.

Improved mechanical ventilation
The improved mechanical ventilation system has a heat recovery efficiency of 0,85 and the specific power for air transportation, SEL is 1,20 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,10 l/s per m^2 gross floor area.

Airing at summer
The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV
The solar cell, PV system has a peak power of 165 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. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 unit and connection		All	60.752	2.038	30
Loft		120 + 45 mm	693	0	50
		120 + 70	701		
		120 + 95	706		
		120 +120	727		
		120 +145	744		
		120 +170	768		
		120 +195	779		
		120 +220	803		
		120 +245	820		
Wall		125 mm	2.339	0	80
		150	2.398		
		190	2.461		
		250	2.559		
		300	2.677		
Basement wall		100 mm	4.340	0	80
		125	4.421		
		150	4.506		
		200	4.671		
		250	4.837		
Basement floor		100 mm	537	0	80
		150	571		
		200	605		
		300	674		
		350	720		
		425	772		
Windows		B	2.899	0	30
		A	3.658		
Mechanical ventilation		Standard	170.763	5.226	30
		Improved	204.916	6.271	
PV	1:	1,40 kWp	18.100 + 5.000	2 % p.a.	20 (10)
+ inverter	2:	2,20	25.640 + 7.400		
	3:	3,00	33.180 + 7.400		
	4:	4,30	43.680 +10.800		
	6:	6,00	57.160 +13.200		
	9:	9,00	82.940 +13.200		
	12:	12,00	108.720 +17.200		

The table on next page 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 of the basement walls, insulation of the floor in the basement, 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 2018, BR18 is tighter than the point of cost optimality, showing a gap of -13 % for the solution without PV and a gap of - 16 % for the solution with PV. For Buildings 2020 where PV is needed to fulfill the requirement the over-performance increases to a gap of - 26 %.

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

Code	Loft	Wall	B.w.	B.f.	Window	Vent.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
MFN.DH.0000.B.S.No	165	125	100	100	B	St.	No	48,78	2.755	3.503
MFN.DH.1000.B.S.No	190	125	100	100	B	St.	No	48,27	2.754	3.496
MFN.DH.2000.B.S.No	215	125	100	100	B	St.	No	47,86	2.752	3.489
MFN.DH.3000.B.S.No	240	125	100	100	B	St.	No	47,56	2.755	3.489
MFN.DH.4000.B.S.No	265	125	100	100	B	St.	No	47,30	2.758	3.488
MFN.DH.5000.B.S.No	290	125	100	100	B	St.	No	47,08	2.762	3.490
MFN.DH.4100.B.S.No	265	150	100	100	B	St.	No	45,87	2.772	3.481
MFN.DH.4200.B.S.No	265	190	100	100	B	St.	No	44,30	2.786	3.472
MFN.DH.4300.B.S.No	265	250	100	100	B	St.	No	42,77	2.816	3.476
MFN.DH.4210.B.S.No	265	190	125	100	B	St.	No	44,02	2.790	3.471
MFN.DH.4220.B.S.No	265	190	150	100	B	St.	No	43,82	2.794	3.472
MFN.DH.4211.B.S.No	265	190	125	150	B	St.	No	43,65	2.794	3.470
MFN.DH.4212.B.S.No	265	190	125	200	B	St.	No	43,41	2.799	3.471
MFN.DH.4211.A.S.No	265	190	125	150	A	St.	No	39,15	2.912	3.571
MFN.DH.4211.A.I.No	265	190	125	150	A	Imp.	No	35,43	2.936	3.545
MFN.DH.4211.B.I.No	265	190	125	150	B	Imp.	No	39,94	2.818	3.444
MFN.DH.4211.B.I.PV1	265	190	125	150	B	Imp.	PV1	37,47	2.841	3.454
MFN.DH.4211.B.I.PV2	265	190	125	150	B	Imp.	PV2	36,06	2.849	3.467
MFN.DH.4211.B.I.PV3	265	190	125	150	B	Imp.	PV3	34,65	2.851	3.475
MFN.DH.8235.A.I.No	365	190	200	425	A	Imp.	No	33,54	2.999	3.576
MFN.DH.8235.A.I.PV2	365	190	200	425	A	Imp.	PV2	29,66	3.029	3.599
MFN.DH.4211.A.I.PV3	265	190	125	150	A	Imp.	PV3	30,14	2.969	3.576

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		Base. wall		Base. floor	
	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	155	0,196	125	0,251	100	0,387	100	0,277	100	0,158
1	190	0,161	150	0,212	125	0,317	125	0,234	150	0,131
2	255	0,120	190	0,170	150	0,269	150	0,203	200	0,112
3	310	0,099	250	0,130	200	0,199	200	0,160	300	0,086
4	370	0,083	300	0,109	245	0,165	250	0,132	350	0,077
5	470	0,066			270	0,151			425	0,067
6					295	0,139				

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.

Windows
Windows are energy class B and A in accordance with the requirements in BR 18 for 2018 and 2020.

Standard mechanical ventilation
The standard mechanical ventilation system has an average air exchange rate of 1,10 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 2,10 kJ/m^3.

Improved mechanical ventilation
The improved mechanical ventilation system has a heat recovery efficiency of 0,85 and the specific power for air transportation, SEL is 1,50 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,10 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 at day time. At night time the air exchange rate in average is up till 2,40 l/s per m^2 gross floor area.

Standard lighting system
Installed power in the office areas is 8 W/m^2. There are automatic continuous daylight control in the lighting zones.

Improved lighting system
Installed power in office areas is reduced to 5 W/m^2 by the use of LED lighting.

Solar cells, PV

The solar cell, PV system has a peak power of 165 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted with a slope of 20º on the flat roof. The horizontal cut off of 5º for the first row of cells and 10º for the next rows of cells The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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	78.399	2.420	30
Flat roof		135+20 mm	433	0	40
		170+20	465		
		235+20	541		
		290+20	600		
		350+20	638		
		450+20	702		
Walls, heavy		125 mm	2.339	0	80
		150	2.398		
		190	2.461		
		250	2.559		
		300	2.677		
Walls, light		100 mm	1.571	0	40
		125	1.626		
		150	1.649		
		200	1.766		
		245	1.904		
		270	1.907		
		295	1.939		
Basement wall		100 mm	4.340	0	80
		125	4.421		
		150	4.506		
		200	4.671		
		250	4.837		
Basement floor		100 mm	537	0	80
		150	571		
		200	605		
		300	674		
		350	720		
		425	772		
Windows		B	2.899	0	30
		A	3.658		
Mechanical ventilation		Standard	1.014	25	30
		Improved	1.217		
Lighting		Standard	216	0	20
		Improved	259		
PV	1:	1,40 kWp	18.100 + 5.000	2 % p.a.	20 (10)
+ inverter	2:	2,20	25.640 + 7.400		
	3:	3,00	33.180 + 7.400		
	4:	4,30	43.680 +10.800		
	6:	6,00	57.160 +13.200		
	9:	9,00	82.940 +13.200		
	12:	12,00	108.720 +17.200		

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 walls, insulation of the floor in the basement, 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.

A major power input from PV on the large, solar exposed roof is in this case beyond cost optimality from a financial perspective, but not from a macro economical perspective. The macro economical cost of establishing PV is lower in the grit compared to individual PV on the buildings. For that reason and because not all buildings can expect to have a solar exposed roof with free space for PV, it can be a good question, if the power from PV should be included in finding the cost optimal point.

For the office building with district heating and a cost optimal point set without PV the energy frame requirement in the Danish Building Regulations 2018, BR18 is tighter than the point of cost optimality, showing a gap of - 28 % for the solution without PV and a gap of - 23 % for the solution with PV. For Buildings 2020 where PV is needed to fulfill the requirement the over-performance increases to a gap of - 40 %.

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

Code	Roof	W.h.	W.l	B.W.	B.F.	Win.	Vent.	Light	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	mm	Class	Type	Type	-	kWh/m^2	DKK/m^2	DKK/m^2
OBN.DH.00000.B.S.S.No	155	125	100	100	100	B	St.	St.	No	63,13	2.672	2.792
OBN.DH.10000.B.S.S.No	190	125	100	100	100	B	St.	St.	No	62,64	2.677	2.794
OBN.DH.20000.B.S.S.No	255	125	100	100	100	B	St.	St.	No	62,07	2.686	2.798
OBN.DH.01000.B.S.S.No	155	150	100	100	100	B	St.	St.	No	62,75	2.675	2.792
OBN.DH.02000.B.S.S.No	155	190	100	100	100	B	St.	St.	No	62,35	2.678	2.792
OBN.DH.03000.B.S.S.No	155	250	100	100	100	B	St.	St.	No	61,96	2.685	2.794
OBN.DH.02100.B.S.S.No	155	190	125	100	100	B	St.	St.	No	61,54	2.681	2.790
OBN.DH.02200.B.S.S.No	155	190	150	100	100	B	St.	St.	No	60,99	2.682	2.787
OBN.DH.02300.B.S.S.No	155	190	200	100	100	B	St.	St.	No	60,20	2.692	2.792
OBN.DH.02210.B.S.S.No	155	190	150	125	100	B	St.	St.	No	60,81	2.685	2.789
OBN.DH.02201.B.S.S.No	155	190	150	100	150	B	St.	St.	No	60,71	2.685	2.788
OBN.DH.02200.A.S.S.No	155	190	150	100	100	A	St.	St.	No	52,95	2.794	2.847
OBN.DH.02200.B.I.S.No	155	190	150	100	100	B	Imp.	St.	No	56,12	2.816	2.862
OBN.DH.02200.B.S.I.No	155	190	150	100	100	B	St.	Imp.	No	55,85	2.707	2.753
OBN.DH.02200.B.S.I.PV3	155	190	150	100	100	B	St.	Imp.	PV3	54,19	2.717	2.749
OBN.DH.02200.B.S.I.PV6	155	190	150	100	100	B	St.	Imp.	PV6	52,53	2.723	2.742
OBN.DH.02200.B.S.I.PV12	155	190	150	100	100	B	St.	Imp.	PV12	49,26	2.732	2.713
OBN.DH.02200.B.S.I.PV24	155	190	150	100	100	B	St.	Imp.	PV24	42,74	2.746	2.709
OBN.DH.02200.B.S.I.PV36	155	190	150	100	100	B	St.	Imp.	PV36	*36,19*	*2.784*	*2.698*
OBN.DH.02200.B.S.I.PV48	155	190	150	100	100	B	St.	Imp.	PV48	32,75	2.821	2.725
OBN.DH.42333.A.I.I.No	370	190	200	200	200	A	Imp.	Imp.	No	39,99	2.890	2.809
OBN.DH.42333.A.I.I.PV12	370	190	200	200	200	A	Imp.	Imp.	PV12	33,41	2.916	2.784

If PV is included in setting the cost optimal point in relation to the requirement in BR18 the result will be a gap of 11 % for the solution without PV and a gap of 18 % for the solution with PV. For Buildings 2020 where PV is needed to fulfill the requirement the gap will be - 8 %.

Sensitivity analysis

Sensitivity analysis are performed with a higher energy price development of + 2,0 % p.a. and with a higher discount rate of 4,0 % p.a. and with a higher interest rate of 3,0 % 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.

Some change of the location of the cost optimal point can be observed from the sensitivity analysis in relation to the improvement of the building envelope in the single family house. A + 2,0 % p.a. higher energy price development lower the cost optimal point by 3,56 kWh/m^2 equivalent to 6,1 %-point. An increase in interest rate to 3,0 % p.a. will raise the cost optimal point by 8,92 kWh/m^2 equivalent to 15,2 %-point. The specific improvement packages where the optimum changes are highlighted with bold underline.

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 4,0 & 3,0 % 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
SFN.DH.000C.B.NV.No	76,85	4.744	6.335	4.468	5.805
SFN.DH.100C.B.NV.No	74,66	4.730	6.283	4.462	5.785
SFN.DH.200C.B.NV.No	72,95	4.718	6.242	4.457	<u>5.768</u>
SFN.DH.300C.B.NV.No	71,64	4.724	6.225	4.468	5.774
SFN.DH.400C.B.NV.No	70,51	4.728	6.210	4.478	5.778
SFN.DH.500C.B.NV.No	69,63	4.741	<u>6.208</u>	4.494	5.792
SFN.DH.401C.B.NV.No	67,49	4.721	6.147	4.483	<u>5.764</u>
SFN.DH.402C.B.NV.No	65,79	4.726	6.119	4.496	5.769
SFN.DH.403C.B.NV.No	63,59	4.749	6.096	4.531	5.794
SFN.DH.404C.B.NV.No	62,83	4.770	<u>6.100</u>	4.558	5.821
SFN.DH.413C.B.NV.No	61,83	4.769	6.080	4.561	<u>5.818</u>
SFN.DH.423C.B.NV.No	59,25	4.786	6.045	4.591	5.836
SFN.DH.433C.B.NV.No	57,43	4.823	<u>6.042</u>	4.640	5.880
SFN.DH.423B.B.NV.No	58,74	4.783	6.033	4.590	5.831
SFN.DH.423A.B.NV.No	58,31	4.839	6.071	4.653	5.901
SFN.DH.423B.B.MV.No	51,22	5.183	6.582	4.932	6.263
SFN.DH.423B.A.NV.No	53,12	4.889	6.082	4.717	5.958
SFN.DH.423B.B.NV.PV1	45,56	5.007	6.169	4.810	6.027
SFN.DH.423B.B.NV.PV2	38,02	5.089	6.230	4.896	6.113
SFN.DH.724B.B.NV.No	55,85	4.837	6.032	4.660	5.895
SFN.DH.724B.B.MV.No	48,63	5.240	6.590	5.004	6.331
SFN.DH.825A.A.MV.No	<u>40,89</u>	<u>5.434</u>	<u>6.665</u>	<u>5.235</u>	<u>6.559</u>
SFN.DH.724B.B.MV.PV1	<u>35,45</u>	<u>5.464</u>	<u>6.731</u>	<u>5.224</u>	<u>6.434</u>
SFN.DH.835A.A.MV.No	39,06	5.568	6.741	5.389	6.723
SFN.DH.835A.A.MV.PV1	25,88	5.792	6.877	5.609	6.919

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 4,0 & 3,0 % p.a.	
Code	Energy kWh/m²	NPV-m DKK/m²	NPV-f DKK/m²	NPV-m DKK/m²	NPV-f DKK/m²
OBN.DH.00000.B.S.S.No	63,13	2.759	2.999	2.770	2.999
OBN.DH.10000.B.S.S.No	62,64	2.763	3.000	2.776	3.003
OBN.DH.20000.B.S.S.No	62,07	2.771	3.002	2.785	3.010
OBN.DH.01000.B.S.S.No	62,75	2.761	2.998	2.774	3.001
OBN.DH.02000.B.S.S.No	62,35	2.764	2.997	2.778	3.003
OBN.DH.03000.B.S.S.No	61,96	2.770	2.998	2.785	3.009
OBN.DH.02100.B.S.S.No	61,54	2.766	2.993	2.781	3.004
OBN.DH.02200.B.S.S.No	60,99	2.766	2.989	2.782	3.003
OBN.DH.02300.B.S.S.No	60,20	2.776	2.992	2.794	3.012
OBN.DH.02210.B.S.S.No	60,81	2.769	2.990	2.786	3.006
OBN.DH.02201.B.S.S.No	60,71	2.769	2.989	2.786	3.006
OBN.DH.02200.A.S.S.No	52,95	2.869	3.030	2.904	3.093
OBN.DH.02200.B.I.S.No	56,12	2.896	3.049	2.925	3.106
OBN.DH.02200.B.S.I.No	55,85	2.786	2.937	2.809	2.983
OBN.DH.02200.B.S.I.PV3	54,19	2.796	2.929	2.819	2.982
OBN.DH.02200.B.S.I.PV6	52,53	2.801	2.917	2.825	2.977
OBN.DH.02200.B.S.I.PV12	49,26	2.809	2.895	2.835	2.968
OBN.DH.02200.B.S.I.PV24	42,74	2.832	2.863	2.862	2.959
OBN.DH.02200.B.S.I.PV36	*36,19*	*2.855*	*2.840*	*2.888*	*2.956*
OBN.DH.02200.B.S.I.PV48	32,75	2.892	2.865	2.925	2.985
OBN.DH.42333.A.I.I.No	39,99	2.957	2.957	3.012	3.104
OBN.DH.42333.A.I.I.PV12	33,41	2.980	2.916	3.038	3.089

In the office building no change of the location of the cost optimal point can be observed from the sensitivity analysis in relation to the improvement of the 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.

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 data used are extracted from the tables in the previous sections of the report.

Individual building envelope elements

The cost optimal level of insulation in the building envelope elements and the requirements in BR18 to the same elements is shown in the tables below.

The component requirements in them self has in general a significant gap to cost optimality especially in the dwellings. It shows a wide flexibility for the designer of a new building to use the solution for the component in the building 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 gap is smaller in the case of heat pump heating and in the case of offices.

EU cost-optimal level and Danish energy requirement level in BR18 in relation to constructions in the building envelope of new buildings. 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 %
Loft	265	0,135	180	0,200	48
Heavy wall	190	0,163	100	0,300	84
Slap on ground, floor heating	300	0,092	80	0,200	117

* Approx.

EU cost-optimal level and Danish energy requirement level in BR18 in relation to constructions in the building envelope of new buildings. Single family house with heat pump.

	EU: mm insul.	U-value W/m^2 K	DK: mm insul. *	U-value W/m^2 K	Gap %
Loft	265	0,135	180	0,200	48
Heavy wall	125	0,229	100	0,300	31
Slap on ground, floor heating	200	0,122	80	0,200	64

* Approx.

EU cost-optimal level and Danish energy requirement level in BR18 in relation to constructions in the building envelope of new buildings. Multifamily house with district heating.

	EU: mm insul.	U-value W/m^2 K	DK: mm insul*.	U-value W/m^2 K	Gap %
Loft	265	0,135	180	0,200	48
Heavy wall	190	0,170	100	0,300	76
Basement wall	125	0,234	90	0,300	28
Basement floor	150	0,131	80	0,200	53

* Approx.

EU cost-optimal level and Danish energy requirement level in BR18 in relation to constructions in the building envelope of new buildings. Office building with district heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul*.	U-value W/m² K	Gap %
Flat roof	155	0,196	150	0,200	2
Heavy wall	190	0,170	100	0,300	76
Light wall	150	0,269	143	0,300	12
Basement wall	100	0,277	90	0,300	8
Basement floor	100	0,158	80	0,200	27

* Approx.

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 BR18 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 with district heating the constructions used to comply with the requirement to the heat loss of the building envelope in BR18 is cost optimal or beyond cost optimal with a gap up till - 21 %. For Buildings 2020 the over-performance increases to a gap of - 20 % to - 27 %.

In the single family house reference building with heat pump heating the constructions used to comply with the requirement to the heat loss of the building envelope in BR18 is beyond cost optimal with a gap of - 21 % to – 33 %. For Buildings 2020 the over-performance increases to a gap of - 27 % to - 43 %.

In the multifamily house reference building with district heating the result is a gap in relation to the cost optimality of the constructions used to comply with the requirement of up to 25 % for both BR18 and Buildings 2020. The results for the multifamily house indeed show the flexibility for the designer to use the solutions he likes.

EU cost-optimal level and Danish energy requirement level in BR18 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/m² K	DK: mm insul.	U-value W/m² K	Gap %
<u>BR18</u>					
Loft	265	0,135	340	0,106	- 21
Heavy wall	190	0,163	190	0,163	0
Slap on ground, floor heating	300	0,092	350	0,082	- 11
<u>Building 2020</u>					
Loft	265	0,135	365	0,099	- 27
Heavy wall	190	0,163	250	0,131	- 20
Slap on ground, floor heating	300	0,092	425	0,071	- 23

In the office reference building with district heating the constructions used to comply with the requirement to the heat loss of the building envelope in BR18 is just cost optimal For Buildings 2020 the gap is 0 % to - 16 %. Also in the office building there is significant flexibility to the designer.

EU cost-optimal level and Danish energy requirement level in BR18 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 heat pump.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
BR18					
Loft	265	0,135	340	0,106	- 21
Heavy wall	125	0,229	190	0,163	- 29
Slap on ground, floor heating	200	0,122	350	0,082	- 33
Building 2020					
Loft	265	0,135	365	0,099	- 27
Heavy wall	125	0,229	250	0,131	- 43
Slap on ground, floor heating	200	0,122	425	0,071	- 42

EU cost-optimal level and Danish energy requirement level in BR18 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 %
BR18					
Loft	265	0,135	265	0,135	0
Heavy wall	190	0,170	150	0,212	25
Basement wall	125	0,234	100	0,277	18
Basement floor	150	0,131	100	0,158	21
Building 2020					
Loft	265	0,135	265	0,135	0
Heavy wall	190	0,170	150	0,212	25
Basement wall	125	0,234	100	0,277	18
Basement floor	150	0,131	100	0,158	21

EU cost-optimal level and Danish energy requirement level in BR18 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 %
BR18					
Flat roof	155	0,196	155	0,196	0
Heavy wall	190	0,170	190	0,170	0
Light wall	150	0,269	150	0,269	0
Basement wall	100	0,277	100	0,277	0
Basement floor	100	0,158	100	0,158	0
Building 2020					
Flat roof	155	0,196	155	0,196	0
Heavy wall	190	0,170	190	0,170	0
Light wall	150	0,269	150	0,269	0
Basement wall	100	0,277	125	0,234	- 16
Basement floor	100	0,158	100	0,158	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 the first section of the chapter the energy frame requirements to existing buildings is analysed. In the second part of the chapter the requirements to the individual elements in the building envelope of existing buildings is analysed. These requirements applies also in the case of minor renovations.

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/m² K	mm	W/m² K	mm	W/m² K	mm	W/m² K
0	100	0,362	0	1,668			0	0,782
1	100+45	0,251	70	0,640			70	0,425
2	100+70	0,215			+125	0,196		
3	100+95	0,188			+200	0,143		
4	100+120	0,167			+250	0,121		
5	100+145	0,150						
6	100+170	0,136						
7	100+195	0,125						
8	100+220	0,115						
9	100+245	0,107						

District heating unit
For district heating the price includes the removal of the old heating unit, the installation of the district heating unit and also the connection to the main pipes inclusive of meter.

New gas boiler
The new condensing gas boiler has an efficiency of 0,98 at full load and 1,07 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 0/35 °C. 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 radiator heating system with a design supply temperature of 70 °C the nominal heating power of the air to water heat pump at test temperatures should be at least 100 % 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 air to water heat pump has a COP at normal test temperatures of 4,10. The heat pump is with on-off control. The relative COP at 50 % part load is 0,93 for the actually used 16 kW heat pump.

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 B and A in accordance with the requirements in BR 18 for 2018 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 basic 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 1,00 kJ/m^3.

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	50.201	2.010	30
Gas boiler		16 kW	54.064	2.163	25
Heat pump		6 (6,5) kW	100.553	4.022	20
Air to water		9 (8,6)	106.153	4.246	
		11 (11,1)	110.353	4.414	
		13 (12,3)	115.353	4.622	
		16 (15,2)	121.121	4.853	
		18 (17,6)	127.177	5.096	
Loft		100	176	0	40
		100+45	258		
		100+70	266		
		100+95	272		
		100+120	299		
		100+145	322		
		100+170	353		
		100+195	370		
		100+220	385		
		100+245	407		
Wall,		0 mm	0	0	60
cavity		70	167		
and then external		+125	1.653		
		+200	1.971		
		+250	2.241		
Slap over basement		0 mm	0	0	60
		70	145		
Windows		B	3.719	0	30
		A	4.465		
Ventilation		Natural	15.000	500	30
		Mechanical	52.657	1.519	
PV	1:	1,40 kWp	19.110 + 5.500	2 % p.a.	20 (10)
+ inverter	2:	2,20	28.204 + 8.140		
	3:	3,00	36.498 + 8.140		
	4:	4,30	48.048 +11.880		
	6:	6,00	62.876 +14.520		

Infiltration
In combination with mechanical ventilation the infiltration is 0,13 l/s per m^2 gross floor area.

Airing at summer
The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV
The solar cell, PV system has a peak power of 165 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 20º and a horizontal cut off of 10º. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

Mechanical ventilation is not tested as measure in the single house from 1930, because it is known from the analysis of the new single house, that mechanical ventilation is not cost efficient.

For the single family house from 1930 with district heating there is a gap of 5 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 58 %

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m^2	DKK/m^2	DKK/m^2
SF30.DH.000.T.NV.No	100	0	0	Th.	NV	No	269,12	2.768	7.007
SF30.DH.000.B.NV.No	100	0	0	B	NV	No	249,41	3.277	7.401
SF30.DH.010.B.NV.No	100	70	0	B	NV	No	166,79	3.285	5.948
SF30.DH.020.B.NV.No	100	195	0	B	NV	No	131,54	4.084	6.257
SF30.DH.011.B.NV.No	100	70	70	B	NV	No	144,96	3.249	5.643
SF30.DH.111.B.NV.No	145	70	70	B	NV	No	135,10	3.254	5.538
SF30.DH.211.B.NV.No	170	70	70	B	NV	No	131,91	3.239	5.486
SF30.DH.311.B.NV.No	195	70	70	B	NV	No	129,53	3.228	5.447
SF30.DH.411.B.NV.No	220	70	70	B	NV	No	127,71	3.240	5.439
SF30.DH.511.B.NV.No	245	70	70	B	NV	No	126,16	3.250	5.433
SF30.DH.611.B.NV.No	270	70	70	B	NV	No	124,97	3.270	5.441
SF30.DH.511.A.NV.No	245	70	70	A	NV	No	122,32	3.347	5.514
SF30.DH.911.A.NV.No	345	70	70	A	NV	No	118,49	3.396	5.526
SF30.DH.921.A.NV.No	345	195	70	A	NV	No	83,95	4.200	5.848
SF30.DH.931.A.NV.No	345	270	70	A	NV	No	79,82	4.395	5.979
SF30.DH.931.A.NV.PV1	345	270	70	A	NV	PV1	52,39	4.706	6.239

For the single family house from 1930 with natural gas heating there is a gap of 4 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 46 %

For the single family house from 1930 with heat pump heating there is a gap of 10 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 49 %

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SF30.Gas.000.T.NV.No	100	0	0	Th.	NV	No	303,34	3.217	7.769
SF30.Gas.000.B.NV.No	100	0	0	B	NV	No	281,70	3.702	8.119
SF30.Gas.010.B.NV.No	100	70	0	B	NV	No	191,06	3.277	6.480
SF30.Gas.020.B.NV.No	100	195	0	B	NV	No	152,35	4.088	6.708
SF30.Gas.011.B.NV.No	100	70	70	B	NV	No	167,15	3.249	6.126
SF30.Gas.211.B.NV.No	170	70	70	B	NV	No	152,67	3.243	5.936
SF30.Gas.411.B.NV.No	220	70	70	B	NV	No	147,95	3.244	5.878
SF30.Gas.511.B.NV.No	245	70	70	B	NV	No	146,34	3.255	5.870
SF30.Gas.611.B.NV.No	270	70	70	B	NV	No	144,96	3.275	5.874
SF30.Gas.511.A.NV.No	245	70	70	A	NV	No	142,07	3.353	5.941
SF30.Gas.721.A.NV.No	225	195	70	A	NV	No	101,42	4.195	6.180
SF30.Gas.721.A.NV.PV1	225	195	70	A	NV	PV1	78,32	4.535	6.203

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SF30.HPA.000.T.NV.No	100	0	0	Th.	NV	No	265,87	4.948	11.678
SF30.HPA.000.B.NV.No	100	0	0	B	NV	No	243,22	5.412	11.833
SF30.HPA.010.B.NV.No	100	70	0	B	NV	No	153,49	4.936	9.516
SF30.HPA.020.B.NV.No	100	195	0	B	NV	No	119,20	5.752	9.565
SF30.HPA.011.B.NV.No	100	70	70	B	NV	No	131,56	4.906	9.031
SF30.HPA.111.B.NV.No	145	70	70	B	NV	No	122,43	4.920	8.866
SF30.HPA.211.B.NV.No	170	70	70	B	NV	No	119,51	4.908	8.795
SF30.HPA.311.B.NV.No	195	70	70	B	NV	No	117,32	4.898	8.742
SF30.HPA.411.B.NV.No	220	70	70	B	NV	No	115,61	4.911	8.723
SF30.HPA.511.B.NV.No	245	70	70	B	NV	No	114,22	4.923	8.708
SF30.HPA.611.B.NV.No	270	70	70	B	NV	No	113,08	4.943	8.708
SF30.HPA.711.B.NV.No	295	70	70	B	NV	No	112,18	4.952	8.700
SF30.HPA.811.B.NV.No	320	70	70	B	NV	No	111,37	4.961	8.694
SF30.HPA.911.B.NV.No	345	70	70	B	NV	No	110,72	4.976	8.698
SF30.HPA.811.A.NV.No	320	70	70	A	NV	No	107,36	5.057	8.739
SF30.HPA.821.A.NV.PV1	320	195	70	A	NV	PV1	56,65	6.412	9.440

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	100	0,333	+0	0,640	+0	0,404	(45)	0,369
1	100+45	0,237	+125	0,196	+45	0,286	100	0,241
2	100+70	0,204	+200	0,143	+70	0,246	150	0,183
3	100+95	0,180	+250	0,121	+95	0,208	200	0,148
4	100+120	0,160					275	0,114
5	100+145	0,144					300	0,106
6	100+170	0,132					400	0,083
7	100+195	0,121						
8	100+220	0,112						
9	100+245	0,104						

District heating unit
For district heating the price includes the removal of the old heating unit, the installation of the district heating unit and also the connection to the main pipes inclusive of meter.

New gas boiler
The new condensing gas boiler has an efficiency of 0,98 at full load and 1,07 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 0/35 °C. 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 radiator heating system with a design supply temperature of 70 °C the nominal heating power of the air to water heat pump at test temperatures should be at least 100 % 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 air to water heat pump has a COP at normal test temperatures of 4,10. The heat pump is with on-off control. The relative COP at 50 % part load is 0,93 for the actually used 16 kW heat pump.

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	50.201	2.010	30
Gas boiler		16 kW	54.064	2.163	25
Heat pump		6 (6,5) kW	100.553	4.022	20
Air to water		9 (8,6)	106.153	4.246	
		11 (11,1)	110.353	4.414	
		13 (12,3)	115.353	4.622	
		16 (15,2)	121.121	4.853	
		18 (17,6)	127.177	5.096	
Solar heating		4,4 m^2	44.876	898	25
incl. storage tank		6,6	52.841	1.057	
Loft		100 mm	176	0	40
		100+45	258		
		100+70	266		
		100+95	272		
		100+120	299		
		100+145	322		
		100+170	353		
		100+195	370		
		100+220	385		
		100+245	407		
Wall, heavy		+0 mm	0	0	60
external		+125	1.486		
		+200	1.804		
		+250	2.074		
Wall, light		+0 mm	0	0	60
external		+45	111		
		+70	117		
		+95	153		
Slap on ground		(45) mm	0	0	60
		100	1.014		
		150	1.053		
		200	1.091		
		275	1.148		
		300	1.223		
		400	1.300		
Windows		B	3.719	0	30
		A	4.465		
Ventilation		Natural	15.000	500	30
		Mechanical	52.657	1.519	
PV	1:	1,40 kWp	19.110 + 5.500	2 % p.a.	20 (10)
+ inverter	2:	2,20	28.204 + 8.140		
	3:	3,00	36.498 + 8.140		
	4:	4,30	48.048 +11.880		
	6:	6,00	62.876 +14.520		

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 B and A in accordance with the requirements in BR 18 for 2018 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 basic 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 1,00 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,13 l/s per m^2 gross floor area.

Airing at summer
The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV
The solar cell, PV system has a peak power of 165 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 10^o. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

The tables on the next 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 and PV. For each of the packages the primary energy demand, the macro economical net present value and the financial net present value is shown.

Mechanical ventilation is not tested as measure in the single house from 1960, because it is known from the analysis of the new single house, that mechanical ventilation is not cost efficient.

For the single family house from 1960 with district heating there is a gap of 10 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 51 %.

For the single family house from 1960 with natural gas heating there is a gap of 10 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is not needed and there is a negative gap of - 48 %.

For the single family house from 1960 with heat pump heating there is a gap of 20 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 39 %.

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	PV -	Energy kWh/m²	NPV-m DKK/m²	NPV-f DKK/m²
SF60.DH.0000.Th.NV.No	100	0	0	(45)	Th.	NV	No	165,45	2.487	4.964
SF60.DH.0000.B.NV.No	100	0	0	(45)	B	NV	No	137,57	3.121	5.470
SF60.DH.1000.B.NV.No	145	0	0	(45)	B	NV	No	129,20	3.136	5.393
SF60.DH.2000.B.NV.No	170	0	0	(45)	B	NV	No	126,30	3.124	5.346
SF60.DH.3000.B.NV.No	195	0	0	(45)	B	NV	No	124,21	3.115	5.313
SF60.DH.4000.B.NV.No	220	0	0	(45)	B	NV	No	122,45	3.127	5.306
SF60.DH.5000.B.NV.No	245	0	0	(45)	B	NV	No	121,06	3.138	5.303
SF60.DH.6000.B.NV.No	270	0	0	(45)	B	NV	No	120,01	3.158	5.314
SF60.DH.5100.B.NV.No	245	125	0	(45)	B	NV	No	98,19	3.723	5.565
SF60.DH.5010.B.NV.No	245	0	45	(45)	B	NV	No	119,06	3.142	5.282
SF60.DH.5020.B.NV.No	245	0	70	(45)	B	NV	No	118,36	3.138	5.269
SF60.DH.5030.B.NV.No	245	0	95	(45)	B	NV	No	117,66	3.139	5.262
SF60.DH.5031.B.NV.No	245	0	95	100	B	NV	No	111,03	3.809	5.806
SF60.DH.5032.B.NV.No	245	0	95	150	B	NV	No	108,13	3.816	5.776
SF60.DH.5033.B.NV.No	245	0	95	200	B	NV	No	106,31	3.830	5.767
SF60.DH.5034.B.NV.No	245	0	95	275	B	NV	No	104,63	3.859	5.773
SF60.DH.5030.A.NV.No	245	0	95	(45)	A	NV	No	112,81	3.271	5.377
SF60.DH.5030.B.MV.No	245	0	95	(45)	B	MV	No	113,85	3.695	6.084
SF60.DH.5030.A.MV.No	245	0	95	(45)	A	MV	No	107,47	3.817	6.157
SF60.DH.9230.A.NV.No	345	200	95	(45)	A	NV	No	84,05	4.051	5.761
SF60.DH.9230.A.NV.PV1	345	200	95	(45)	A	NV	PV1	57,87	4.347	5.660

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 mm	W.h. mm	W.l mm	Slap. mm	Win. Class	Vent. Type	PV -	Energy kWh/m²	NPV-m DKK/m²	NPV-f DKK/m²
SF60.Gas.0000.Th.N.No	100	0	0	(45)	Th.	NV	No	184,21	2.518	5.488
SF60.Gas.0000.B.N.No	100	0	0	(45)	B	NV	No	153,73	3.162	5.933
SF60.Gas.1000.B.N.No	145	0	0	(45)	B	NV	No	144,70	3.182	5.840
SF60.Gas.2000.B.N.No	170	0	0	(45)	B	NV	No	141,52	3.170	5.786
SF60.Gas.3000.B.N.No	195	0	0	(45)	B	NV	No	139,16	3.161	5.747
SF60.Gas.4000.B.N.No	220	0	0	(45)	B	NV	No	137,32	3.175	5.738
SF60.Gas.5000.B.N.No	245	0	0	(45)	B	NV	No	135,77	3.186	5.731
SF60.Gas.6000.B.N.No	270	0	0	(45)	B	NV	No	134,65	3.207	5.740
SF60.Gas.5100.B.N.No	245	125	0	(45)	B	NV	No	110,79	3.779	5.944
SF60.Gas.5010.B.N.No	245	0	45	(45)	B	NV	No	133,53	3.191	5.705
SF60.Gas.5020.B.N.No	245	0	70	(45)	B	NV	No	132,82	3.187	5.692
SF60.Gas.5030.B.N.No	245	0	95	(45)	B	NV	No	132,09	3.189	5.683
SF60.Gas.5031.B.N.No	245	0	95	100	B	NV	No	124,81	3.861	6.212
SF60.Gas.5030.A.N.No	245	0	95	(45)	A	NV	No	126,71	3.322	5.787
SF60.Gas.9230.A.N.No	345	200	95	(45)	A	NV	No	95,33	4.113	6.109
SF60.Gas.9230.A.N.No	345	200	95	(45)	A	NV	No	69,17	4.410	6.350

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
SF60.HPA.0000.Th.NV.No	100	0	0	(45)	Th.	NV	No	141,38	3.859	7.933
SF60.HPA.0000.B.NV.No	100	0	0	(45)	B	NV	No	112,36	4.494	8.181
SF60.HPA.1000.B.NV.No	145	0	0	(45)	B	NV	No	104,31	4.514	8.046
SF60.HPA.2000.B.NV.No	170	0	0	(45)	B	NV	No	101,06	4.504	7.980
SF60.HPA.3000.B.NV.No	195	0	0	(45)	B	NV	No	99,63	4.496	7.933
SF60.HPA.4000.B.NV.No	220	0	0	(45)	B	NV	No	97,98	4.509	7.915
SF60.HPA.5000.B.NV.No	245	0	0	(45)	B	NV	No	96,70	4.521	7.904
SF60.HPA.6000.B.NV.No	270	0	0	(45)	B	NV	No	95,72	4.543	7.908
SF60.HPA.5100.B.NV.No	245	125	0	(45)	B	NV	No	76,12	5.128	8.042
SF60.HPA.5010.B.NV.No	245	0	45	(45)	B	NV	No	94,80	4.527	7.869
SF60.HPA.5020.B.NV.No	245	0	70	(45)	B	NV	No	94,15	4.524	7.852
SF60.HPA.5030.B.NV.No	245	0	95	(45)	B	NV	No	93,56	4.525	7.842
SF60.HPA.5031.B.NV.No	245	0	95	100	B	NV	No	87,54	5.201	8.349
SF60.HPA.5030.A.NV.No	245	0	95	(45)	A	NV	No	88,70	4.660	7.920
SF60.HPA.9030.A.NV.No	345	0	95	(45)	A	NV	No	85,94	4.717	7.928
SF60.HPA.9030.A.MV.No	345	0	95	(45)	A	MV	No	83,14	4.284	8.647
SF60.HPA.9030.A.MV.PV1	345	0	95	(45)	A	MV	PV1	56,98	5.581	8.920

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/m^2 K	mm	W/m^2 K	Mm	W/m^2 K
0	100	0,362	+0	1,668	0	0,782
1	100+45	0,251	+125	0,267	70	0,425
2	100+70	0,215	+200	0,178		
3	100+95	0,188	+250	0,146		
4	100+120	0,167				
5	100+145	0,150				
6	100+170	0,136				
7	100+195	0,125				
8	100+220	0,115				
9	100+245	0,107				

District heating unit
For district heating the price includes the removal of the old heating unit, the installation of the district heating unit and also the connection to the main pipes inclusive of meter.

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 B and A in accordance with the requirements in BR 18 for 2018 and 2020.

Balanced mechanical ventilation
The mechanical ventilation has an basic 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 at average ventilation flow.

Improved mechanical ventilation
The improved mechanical ventilation has a heat recovery efficiency of 0,85 and a specific power for air transportation, SEL of 1,50 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,13 l/s per m^2 gross floor area.

Airing at summer

The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV

The solar cell, PV system has a peak power of 165 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 25º and a horizontal cut off of 5º. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 (m^2)	Maintenance etc. DKK/unit (m^2)	Life time years
District heating unit	All	97.320	3.866	30
Loft	100	161	0	40
	100+45	236		
	100+70	244		
	100+95	250		
	100+120	277		
	100+145	300		
	100+170	331		
	100+195	348		
	100+220	363		
	100+245	385		
Walls, heavy	+0	0	0	60
external	+125	1.431		
	+200	1.749		
	+250	2.019		
Basement slap	0 mm	0	0	60
	70	140		
Windows	B	3.256	0	30
	A	4.066		
Natural ventilation	Standard	50	1	30
Mechanical ventilation	Standard	500	5	
	Improved	600	6	
PV	1:	1,40 kWp	19.110 + 5.500	2 % p.a.
+ inverter	2:	2,20	28.204 + 8.140	
	3:	3,00	36.498 + 8.140	
	4:	4,30	48.048 +11.880	
	6:	6,00	62.876 +14.520	

The table on next page list the packages of energy saving measures calculated for the existing multifamily house from 1930 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 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.

For the multifamily house from 1930 with district heating PV is needed to fulfil both the renovation class 2 and the renovation class 1 requirement. For the multi family house from 1930 with district heating there is a gap of 89 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 there is a negative gap of - 9 %.

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
MF30.DH.000.Th.NV.No	100	0	0	Th.	NV	No	142,90	1.215	3.010
MF30.DH.000.B.NV.No	100	0	0	B	NV	No	129,08	1.495	3.218
MF30.DH.100.B.NV.No	145	0	0	B	NV	No	126,62	1.495	3.190
MF30.DH.200.B.NV.No	170	0	0	B	NV	No	125,83	1.492	3.178
MF30.DH.300.B.NV.No	195	0	0	B	NV	No	125,23	1.489	3.168
MF30.DH.400.B.NV.No	220	0	0	B	NV	No	124,77	1.492	3.166
MF30.DH.500.B.NV.No	245	0	0	B	NV	No	124,40	1.494	3.164
MF30.DH.600.B.NV.No	270	0	0	B	NV	No	124,09	1.499	3.166
MF30.DH.700.B.NV.No	295	0	0	B	NV	No	123,84	1.501	3.166
MF30.DH.501.B.NV.No	245	0	70	B	NV	No	119,71	1.490	3.102
MF30.DH.501.B.NV.PV1	245	0	70	B	NV	PV1	118,29	1.511	3.103
MF30.DH.501.B.NV.PV15	245	0	70	B	NV	PV15	104,43	1.626	3.427
MF30.DH.511.B.NV.No	245	125	70	B	NV	No	55,29	1.790	2.580
MF30.DH.521.B.NV.No	245	200	70	B	NV	No	51,61	1.901	2.639
MF30.DH.511.A.NV.No	245	125	70	A	NV	No	52,35	1.863	2.642
MF30.DH.511.B.MV.No	245	125	70	B	MV	No	55,66	2.340	3.407
MF30.DH.511.B.iMV.No	245	125	70	B	iMV	No	52,28	2.442	3.485
MF30.DH.511.B.NV.PV2	245	125	70	B	NV	PV2	50,11	1.893	2.701

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/m^2 K	mm	W/m^2 K	mm	W/m^2 K
0	50	0,555	50	0,664	+0	0,459
1	100	0,333	100	0,404	+50	0,286
2	100+45	0,237	100+45	0,286	+100	0,208
3	100+70	0,204	100+70	0,246	+150	0,163
4	100+95	0,180	100+95	0,208		
5	100+120	0,160				
6	100+145	0,144				
7	100+170	0,132				
8	100+195	0,121				
9	100+220	0,112				
10	100+245	0,104				

District heating unit
For district heating the price includes the removal of the old heating unit, the installation of the district heating unit and also the connection to the main pipes inclusive of meter.

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 first for additional insulation possibly in the existing construction width and then for the additional construction and insulation increasing the construction width. Original insulation is maintained in the existing construction.

Windows
Windows are energy class B and A in accordance with the requirements in BR 18 for 2018 and 2020.

Balanced mechanical ventilation
The mechanical ventilation has an basic 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 at average ventilation flow.

Improved mechanical ventilation
The improved mechanical ventilation has a heat recovery efficiency of 0,85 and a specific power for air transportation, SEL of 1,50 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,13 l/s per m^2 gross floor area.

Airing at summer
The air exchange rate in relation to airing at summer time is 3,00 l/s per m^2 gross floor area in average.

Solar cells, PV
The solar cell, PV system has a peak power of 165 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted at the roof with a slope of 25º and a horizontal cut off of 5º. The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 unit		All	97.320	3.866	30
Loft		50	101	0	40
		100	161		
		100+45	236		
		100+70	244		
		100+95	250		
		100+120	277		
		100+145	300		
		100+170	331		
		100+195	348		
		100+220	363		
		100+245	385		
Walls, light		50	0	0	60
		100	38		
		100+45	98		
		100+70	103		
		100+95	135		
Basement slap		0 mm	0	0	60
		50	312		
		100	385		
		150	408		
Windows		B	3.256	0	30
		A	4.066		
Mechanical exhaust		Standard	100	1	30
Mechanical ventilation		Standard	450	5	
		Improved	550	6	
PV	1:	1,40 kWp	19.110 + 5.500	2 % p.a.	20 (10)
+ inverter	2:	2,20	28.204 + 8.140		
	3:	3,00	36.498 + 8.140		
	4:	4,30	48.048 +11.880		
	6:	6,00	62.876 +14.520		

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, balanced mechanical ventilation with heat recovery as an alternative to the mechanical exhaust system and 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 there is a gap of 48 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 17 %.

PV is in this case cost efficient to install on the roof of the building. If PV are included in calculating the point of cost optimal the gap to renovation class 2 will increase to 52 % and the negative gap to renovation class 1 will decrease to – 15 %.

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.	PV	Energy	NPV-m	NPV-f
	mm	mm	mm	Class	Type	-	kWh/m²	DKK/m²	DKK/m²
MF60.DH.000.Th.Exh.No	50	50	0	Th.	Exh.	No	109,84	958	2.419
MF60.DH.000.B.Exh.No	50	50	0	B	Exh.	No	89,16	1.382	2.737
MF60.DH.100.B.Exh.No	100	50	0	B	Exh.	No	84,35	1.362	2.661
MF60.DH.200.B.Exh.No	145	50	0	B	Exh.	No	82,27	1.365	2.640
MF60.DH.300.B.Exh.No	170	50	0	B	Exh.	No	81,56	1.362	2.629
MF60.DH.400.B.Exh.No	195	50	0	B	Exh.	No	81,05	1.359	2.621
MF60.DH.500.B.Exh.No	220	50	0	B	Exh.	No	80,62	1.363	2.619
MF60.DH.600.B.Exh.No	245	50	0	B	Exh.	No	80,28	1.365	2.619
MF60.DH.700.B.Exh.No	270	50	0	B	Exh.	No	80,03	1.371	2.622
MF60.DH.610.B.Exh.No	245	100	0	B	Exh.	No	71,10	1.314	2.457
MF60.DH.620.B.Exh.No	245	145	0	B	Exh.	No	67,19	1.307	2.401
MF60.DH.630.B.Exh.No	245	170	0	B	Exh.	No	65,89	1.300	2.377
MF60.DH.640.B.Exh.No	245	195	0	B	Exh.	No	64,66	1.302	2.365
MF60.DH.641.B.Exh.No	245	195	50	B	Exh.	No	62,05	1.346	2.373
MF60.DH.642.B.Exh.No	245	195	100	B	Exh.	No	60,85	1.352	2.364
MF60.DH.643.B.Exh.No	245	195	150	B	Exh.	No	60,17	1.352	2.355
MF60.DH.643.A.Exh.No	245	195	150	A	Exh.	No	55,98	1.464	2.453
MF60.DH.643.B.MV.No	245	195	150	B	MV	No	45,84	1.702	2.709
MF60.DH.643.B.Exh.PV2	245	195	150	B	Exh.	PV2	58,94	1.364	2.360
MF60.DH.643.B.Exh.PV3	245	195	150	B	Exh.	PV3	*58,49*	*1.365*	*2.341*
MF60.DH.643.B.Exh.PV4	245	195	150	B	Exh.	PV4	57,76	1.361	2.349
MF60.DH.1043.A.Exh.No	345	195	150	A	Exh.	No	55,43	1.479	2.463
MF60.DH.1043.A.Exh.PV10	345	195	150	A	Exh.	PV10	49,65	1.517	2.511

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/m^2 K	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K
0	155	0,196	+0	1,726	50	0,664	+0	0,459
1	190	0,161	+125	0,261	100	0,404	+50	0,286
2	255	0,120	+200	0,154	100+45	0,286	+100	0,208
3	310	0,099	+250	0,127	100+70	0,246	+150	0,163
4	370	0,083			100+95	0,208		
5	470	0,066						

District heating unit
For district heating the price includes the removal of the old heating unit, the installation of the district heating unit and also the connection to the main pipes inclusive of meter.

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 first for additional insulation possinly in the existing construction weith and then for the additional construction and insulation increasing the construction weith. Original insulation is maintained in the existing construction.

Windows
Windows are energy class B and A in accordance with the requirements in BR 18 for 2018 and 2020.

Standard mechanical ventilation system
The standard mechanical ventilation system has an average air exchange rate of 1,10 l/s per m^2 gross floor area due to demand control. In summer the air exchange rate can increase to 1,50 l/s per m^2. The heat recovery efficiency is 0,80 and the minimum inlet temperature is 18 ^oC. The specific power for air transportation, SEL is 2,10 kJ/m^3.

Improved mechanical ventilation system
The improved mechanical ventilation system has a heat recovery efficiency of 0,85 and the specific power for air transportation, SEL is 1,50 kJ/m^3.

Infiltration
In combination with mechanical ventilation the infiltration is 0,13 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 at day time. At night time the air exchange rate in average is up till 2,40 l/s per m^2 gross floor area.

Standard lighting system
Installed power in the office areas is 8 W/m^2. There are automatic continuous daylight control in the lighting zones.

Improved lighting system
Installed power in office areas is reduced to 5 W/m^2 by the use of LED lighting.

Solar cells, PV
The solar cell, PV system has a peak power of 165 Wp/m^2 and a system efficiency, R_p of 0,75. The cells are mounted with a slope of 20^o on the flat roof. The horizontal cut off of 5^o for the first row of cells and 10^o for the next rows of cells The need to change the inverter due to shorter lifetime of the inverter compared to the solar panels is treated separately in the cost calculations.

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 unit	All	97.320	3.866	30
Flat roof	155 mm	476	0	40
	190	512		
	255	595		
	310	660		
	370	702		
	470	772		
Walls, heavy	+0	0	0	60
external	+125	1.431		
	+200	1.749		
	+250	2.019		
Walls, light	50	0	0	60
	100	38		
	100+45	98		
	100+70	103		
	100+95	135		
Basement slap	0 mm	0	0	60
	50	312		
	100	385		
	150	408		
Windows	B	3.256	0	30
	A	4.066		
Mechanical ventilation	Standard	900	10	25
	Improved	1.100	12	
Lighting	Standard	324	0	20
	Improved	389		
PV 1:	1,40 kWp	19.110 + 5.500	2 % p.a.	20 (10)
+ inverter 2:	2,20	28.204 + 8.140		
3:	3,00	36.498 + 8.140		
4:	4,30	48.048 +11.880		
6:	6,00	62.876 +14.520		
9:	9,00	91.230 + 14.520		
12:	12,0	119.590 + 18.920		

The table below 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, 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 there is a gap of 46 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 7 %.

PV is in this case cost efficient to install on the roof of the building. If PV are included in calculating the point of cost optimal the gap to renovation class 2 will increase to 65 % and the gap to renovation class 1 will be converted to a positive gap of 5 %.

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/m^2	DKK/m^2	DKK/m^2
OB60.DH.0000.Th.S.S.No	155	0	50	0	Th.	St.	St.	No	128,40	1.924	2.622
OB60.DH.0000.B.S.S.No	155	0	50	0	B	St.	St.	No	96,74	2.500	2.978
OB60.DH.1000.B.S.S.No	190	0	50	0	B	St.	St.	No	96,08	2.503	2.977
OB60.DH.2000.B.S.S.No	255	0	50	0	B	St.	St.	No	95,33	2.513	2.981
OB60.DH.1100.B.S.S.No	190	125	50	0	B	St.	St.	No	77,69	2.550	2.897
OB60.DH.1200.B.S.S.No	190	200	50	0	B	St.	St.	No	76,41	2.573	2.904
OB60.DH.1110.B.S.S.No	190	125	100	0	B	St.	St.	No	73,98	2.538	2.868
OB60.DH.1120.B.S.S.No	190	125	145	0	B	St.	St.	No	72,34	2.539	2.860
OB60.DH.1130.B.S.S.No	190	125	170	0	B	St.	St.	No	71,80	2.537	2.855
OB60.DH.1140.B.S.S.No	190	125	195	0	B	St.	St.	No	71,28	2.584	2.854
OB60.DH.1140.B.S.S.PV9	190	125	195	0	B	St.	St.	PV9	61,57	2.550	2.802
OB60.DH.1141.B.S.S.No	190	125	195	50	B	St.	St.	No	69,10	2.575	2.865
OB60.DH.1142.B.S.S.No	190	125	195	100	B	St.	St.	No	68,14	2.582	2.863
OB60.DH.1140.A.S.S.No	190	125	195	0	A	St.	St.	No	61,78	2.675	2.927
OB60.DH.1140.B.I.S.No	190	125	195	0	B	Imp.	St.	No	66,57	2.720	2.979
OB60.DH.1140.B.S.I.No	190	125	195	0	B	St.	Imp.	No	66,22	2.586	2.843
OB60.DH.1140.B.S.I.PV6	190	125	195	0	B	St.	Imp.	PV6	62,49	2.608	2.835
OB60.DH.1140.B.S.I.PV12	190	125	195	0	B	St.	Imp.	PV12	*58,80*	*2.621*	*2.829*
OB60.DH.1140.B.S.I.PV18	190	125	195	0	B	St.	Imp.	PV18	55,14	2.638	2.834

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 constructions.

Level	Flat roof		Walls, heavy		Walls, light		Basement slap	
	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K	mm	W/m^2 K
0	155	0,196	+0	0,475	50	0,525	+0	0,385
1	190	0,161	+125	0,244	100	0,404	+50	0,256
2	255	0,120	+200	0,144	100+45	0,286	+100	0,191
3	310	0,099	+250	0,121	100+70	0,246	+150	0,153
4	370	0,083			100+95	0,208		
5	470	0,066						

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, 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 there is a gap of 15 % between the renovation class 2 requirement in BR18 and the point of cost optimal. In relation to renovation class 1 PV is needed and there is a negative gap of - 1 %.

PV is in this case cost efficient to install on the roof of the building. If PV are included in calculating the point of cost optimal the gap to renovation class 2 will increase to 29 % and the gap to renovation class 1 will be converted to a positive gap of 11 %.

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
OB80.DH.0000.Th.S.S.No	155	0	70	0	Th.	St.	St.	No	108,10	1.831	2.438
OB80.DH.0000.B.S.S.No	155	0	70	0	B	St.	St.	No	77,84	2.413	2.807
OB80.DH.1000.B.S.S.No	190	0	70	0	B	St.	St.	No	77,23	2.417	2.806
OB80.DH.2000.B.S.S.No	255	0	70	0	B	St.	St.	No	76,52	2.427	2.811
OB80.DH.1100.B.S.S.No	190	125	70	0	B	St.	St.	No	74,51	2.535	2.868
OB80.DH.1010.B.S.S.No	190	0	100	0	B	St.	St.	No	75,49	2.414	2.795
OB80.DH.1020.B.S.S.No	190	0	145	0	B	St.	St.	No	73,83	2.414	2.786
OB80.DH.1030.B.S.S.No	190	0	170	0	B	St.	St.	No	73,27	2.412	2.782
OB80.DH.1040.B.S.S.No	190	0	195	0	B	St.	St.	No	72,75	2.414	2.781
OB80.DH.1041.B.S.S.No	190	0	195	50	B	St.	St.	No	71,10	2.453	2.797
OB80.DH.1042.B.S.S.No	190	0	195	100	B	St.	St.	No	70,28	2.460	2.796
OB80.DH.1040.A.S.S.No	190	0	195	0	A	St.	St.	No	72,75	2.594	2.941
OB80.DH.1040.B.I.S.No	190	0	195	0	B	Imp.	St.	No	68,06	2.596	2.906
OB80.DH.1040.B.S.I.No	190	0	195	0	B	St.	Imp.	No	67,71	2.462	2.770
OB80.DH.1040.B.S.I.PV1	190	0	195	0	B	St.	Imp.	PV1	66,84	2.470	2.771
OB80.DH.1040.B.S.I.PV9	190	0	195	0	B	St.	Imp.	PV9	62,15	2.488	2.757
OB80.DH.1040.B.S.I.PV12	190	0	195	0	B	St.	Imp.	PV12	*60,33*	*2.496*	*2.756*
OB80.DH.1040.B.S.I.PV15	190	0	195	0	B	St.	Imp.	PV15	58,49	2.505	2.758
OB80.DH.1040.B.S.I.PV18	190	0	195	0	B	St.	Imp.	PV18	56,64	2.514	2.761

Sensitivity analysis

Sensitivity analysis are performed with a higher energy price development of + 2,0 % p.a. and with a higher discount rate of 4,0 % p.a. and with a higher interest rate of 3,0 % 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.

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 for the existing office building from 1960.

For the office building from 1980 there is a small change in the cost optimum point in relation to the PV power installed in the direction of installation of more PV. The opposite can be observed in the case where there is an additional development of the rates.

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 4,0 & 3,0 % 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
OB60.DH.0000.Th.S.S.No	128,40	2.109	3.011	1.885	2.430
OB60.DH.0000.B.S.S.No	96,74	2.650	3.293	2.505	2.918
OB60.DH.1000.B.S.S.No	96,08	2.652	3.290	2.508	2.920
OB60.DH.2000.B.S.S.No	95,33	2.661	3.293	2.520	2.928
OB60.DH.1100.B.S.S.No	77,69	2.678	3.168	2.580	2.916
OB60.DH.1200.B.S.S.No	76,41	2.700	3.173	2.608	2.936
OB60.DH.1110.B.S.S.No	73,98	2.662	3.130	2.570	2.894
OB60.DH.1120.B.S.S.No	72,34	2.661	3.118	2.572	2.890
OB60.DH.1130.B.S.S.No	71,80	2.658	3.113	2.570	2.887
OB60.DH.1140.B.S.S.No	71,28	2.660	3.111	2.573	2.888
OB60.DH.1140.B.S.S.PV9	61,57	2.665	3.037	2.586	2.823
OB60.DH.1141.B.S.S.No	69,10	2.693	3.116	2.616	2.918
OB60.DH.1142.B.S.S.No	68,14	2.699	3.113	2.624	2.922
OB60.DH.1140.A.S.S.No	61,78	2.785	3.161	2.720	2.997
OB60.DH.1140.B.I.S.No	66,57	2.845	3.230	2.759	3.034
OB60.DH.1140.B.S.I.No	66,22	2.703	3.081	2.622	2.890
OB60.DH.1140.B.S.I.PV6	62,49	2.723	3.064	2.644	2.888
OB60.DH.1140.B.S.I.PV12	*58,80*	*2.734*	*3.052*	*2.657*	*2.886*
OB60.DH.1140.B.S.I.PV18	55,14	2.750	3.053	2.675	2.894

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 4,0 & 3,0 % p.a.	
Code	Energy kWh/m2	NPV-m DKK/m2	NPV-f DKK/m2	NPV-m DKK/m2	NPV-f DKK/m2
OB80.DH.0000.Th.S.S.No	108,10	1.993	2.779	1.801	2.281
OB80.DH.0000.B.S.S.No	77,84	2.541	3.078	2.426	2.780
OB80.DH.1000.B.S.S.No	77,23	2.544	3.076	2.430	2.781
OB80.DH.2000.B.S.S.No	76,52	2.554	3.079	2.442	2.790
OB80.DH.1100.B.S.S.No	74,51	2.660	3.132	2.566	2.893
OB80.DH.1010.B.S.S.No	75,49	2.539	3.061	2.428	2.774
OB80.DH.1020.B.S.S.No	73,83	2.538	3.049	2.430	2.770
OB80.DH.1030.B.S.S.No	73,27	2.535	3.043	2.429	2.767
OB80.DH.1040.B.S.S.No	72,75	2.537	3.041	2.431	2.767
OB80.DH.1041.B.S.S.No	71,10	2.574	3.053	2.476	2.801
OB80.DH.1042.B.S.S.No	70,28	2.580	3.050	2.485	2.806
OB80.DH.1040.A.S.S.No	72,75	2.716	3.201	2.618	2.947
OB80.DH.1040.B.I.S.No	68,06	2.722	3.161	2.617	2.914
OB80.DH.1040.B.S.I.No	67,71	2.580	3.012	2.480	2.770
OB80.DH.1040.B.S.I.PV1	66,84	2.588	3.011	2.489	2.772
OB80.DH.1040.B.S.I.PV9	62,15	2.604	2.987	2.508	2.765
OB80.DH.1040.B.S.I.PV12	*60,33*	*2.611*	*2.983*	*2.516*	*2.766*
OB80.DH.1040.B.S.I.PV15	58,49	2.619	2.982	2.525	2.769
OB80.DH.1040.B.S.I.PV18	56,64	2.627	2.983	2.533	2.774

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 BR18 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 at least 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.

There are small differences in the result for buildings heated by district heating and buildings heated by natural gas.

The result for buildings heated with heat pumps are between the results for buildings 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 elements in the building envelope in case of renovation inclusive of major renovations are in most situations at the point of cost optimal. But differences occurs. In the case of parallel roof the question of increasing the construction height has a gap of 50 % for newer construction with a construction height of 120 mm in the calculations. For older constructions of parallel roof there is no gap. There is also occasional gaps of 22 % for flat roofs in single family houses with district heating and of 30 % for old loft constructions in single family houses with natural gas heating and for large buildings with district heating. Negative gap of -16 % occours for slap on ground insulation below hard floors in single family houses with district heating. Negative gap of -23 % occours for external insulation of heavy solid walls in single family houses with natural gas heating and for large buildings with district heating.

EU cost-optimal level and Danish energy requirement level in BR18 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	245	0,145	240	0,150	4
Loft, older	245	0,150	245	0,150	0
Parallel roof *, newer (120 mm construct.)	190	0,198	120	0,297	50
Parallel roof *, older (95 mm construct.)	165	0,225	165	0,225	0
Flat roof *	190	0,161	155	0,196	22
Heavy solid wall, external insulation	125	0,261	125	0,261	0
Heavy insul. cavity wall, ext. insulation	0	0,640	0	0,640	0
Insulated light wall, additional insulation	95	0,208	95	0,208	0
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	150	0,145	200	0,122	- 16

* Not in the reference buildings.

EU cost-optimal level and Danish energy requirement level in BR18 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	245	0,145	240	0,150	4
Loft, older	320	0,115	245	0,150	30
Parallel roof *, newer (120 mm construct.)	190	0,198	120	0,297	50
Parallel roof *, older (95 mm construct.)	165	0,225	165	0,225	0
Flat roof *	190	0,161	190	0,161	0
Heavy solid wall, external insulation	125	0,261	170	0,200	- 23
Heavy insul. cavity wall, ext. insulation	0	0,640	0	0,640	0
Insulated light wall, additional insulation	95	0,208	95	0,208	0
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	200	0,122	200	0,122	0

* Not in the reference buildings.

EU cost-optimal level and Danish energy requirement level in BR18 in relation to renovation of the constructions in the building envelope. Large buildings with district heating.

	EU: mm insul.	U-value W/m² K	DK: mm insul.	U-value W/m² K	Gap %
Loft, newer	245	0,145	240	0,150	4
Loft, older	320	0,115	245	0,150	30
Parallel roof *, newer (120 mm construct.)	190	0,198	120	0,297	50
Parallel roof *, older (95 mm construct.)	165	0,225	165	0,225	0
Flat roof *	190	0,161	190	0,161	0
Heavy solid wall, external insulation	125	0,261	170	0,200	- 23
Heavy insul. cavity wall, ext. insulation	0	0,640	0	0,640	0
Insulated light wall, additional insulation	95	0,208	95	0,208	0
Slap on ground, wooden floor, insul. above	45	0,369	45	0,369	0
Slap on ground, hard floor, insul. below	200	0,122	200	0,122	0

* Not in the reference buildings.

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.

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.

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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Bygningsreglement 2018 (In Danish), [Danish Building Regulations 2018], Danish Transportation, Building and Housing Agency.

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Produktoversigt 2017 (In Danish) [Product Summary 2017] Organization of Danish Thermal Insulation Suppliers.

SBi 2013:25: Cost-Optimal levels of minimum Energy Perfomance Requirements in the Danish Building Regulations. Danish Building Research Institute - SBi, 2013.

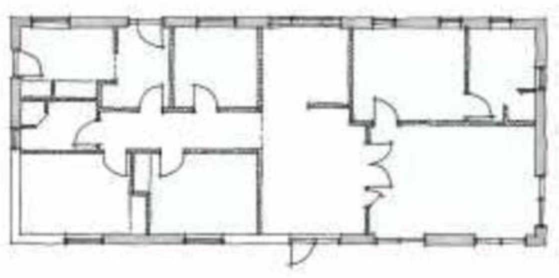
Appendix: Reference buildings

New buildings

New single-family house

North and South facade

East and West gable



Plan

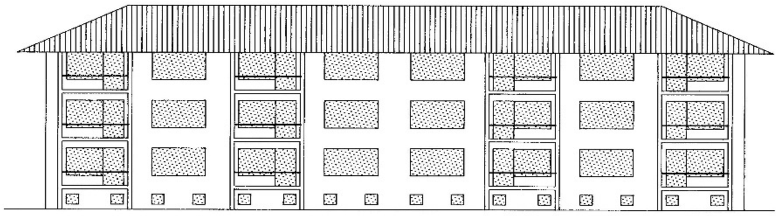
The house has a gross floor area of 149,6 m^2 and includes living room, dining room, 4 bedrooms, kitchen, utility room and two bathrooms.

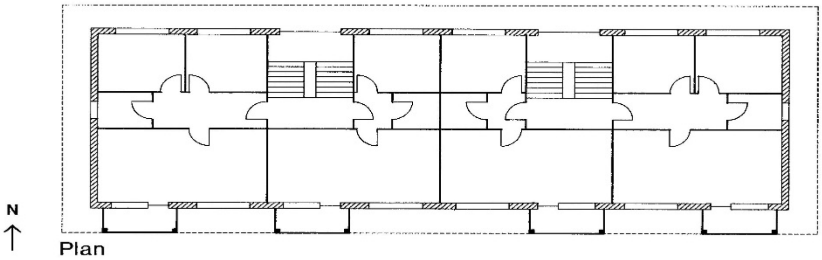
There is an open attic with insulation on the loft. The external wall is an insulated cavity wall with 100 mm light concrete inner wall and a ½ stone brick in the external façade. The top of the foundations are made of insulated light concrete aggregate blocks. The slap on ground is 100 mm concrete with 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 $^{\circ}C$.

Pipes and fittings are insulated in accordance with DS 452.





South facade and plan

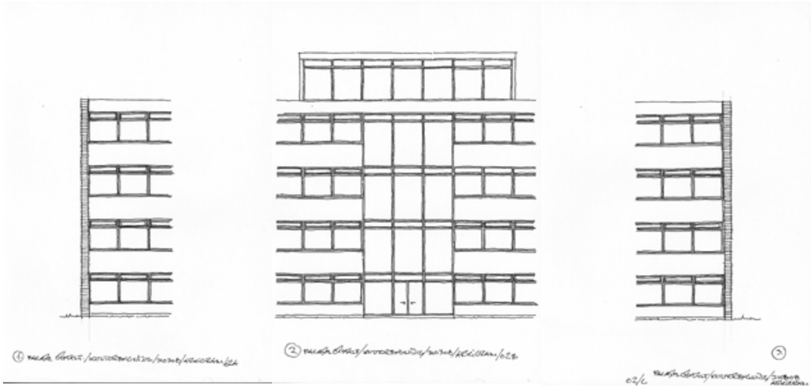
The building is 3 storey with a heated gross floor area of 1080 m², 360 m² gross floor area per storey. There are 6 small apartments of 66 m² each and 6 large apartments of 91 m² each. The window area is 22,5 % compared to the floor area. The major part of window area in the flats is facing South. There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

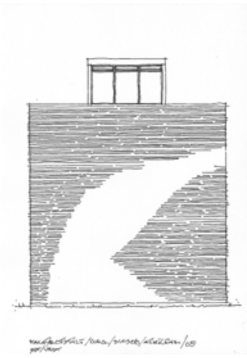
At the starting point there are demand controlled mechanical balanced ventilation with heat recovery in the house with air inlet in the living rooms, exhaust from kitchen and bathrooms and a cooker hood in the kitchen.

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.

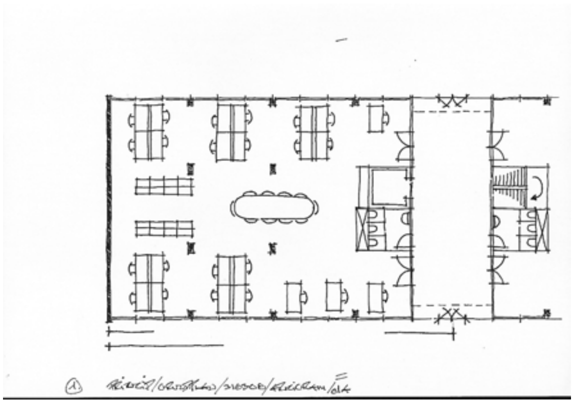
New office building



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 demand controlled average ventilation rate of 1,1 liter/sek. per m² gross floor area. The heat recovery efficiency is 0,80 and the power needed for air transportation, SEL is 2,1 kJ/m³. The airing windows are automatically controlled with the possibility to open during operation hours and at night time. There is mechanical exhaust from the toilets without heat recovery.

The lighting level is 300 lux in the offices and 100 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

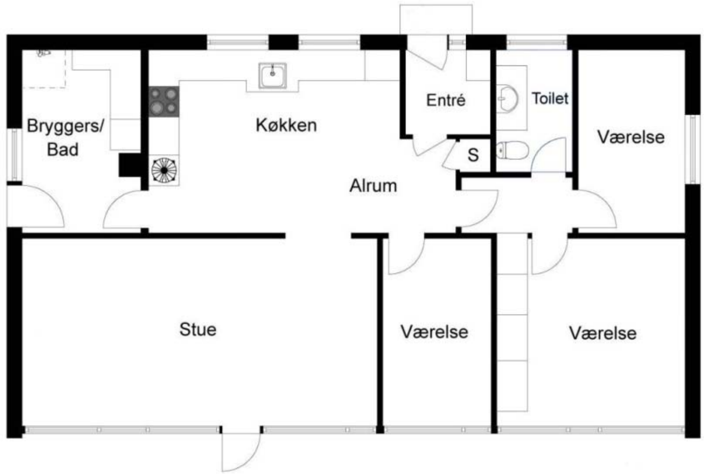
At the starting point there is natural ventilation in the house without any specific ventilation provisions. The airtightness of the building envelop is lacking especial around windows and doors. There is a cooker hood in the kitchen.

The heat supply is either district heating, gas boiler or external air heat pump.

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.

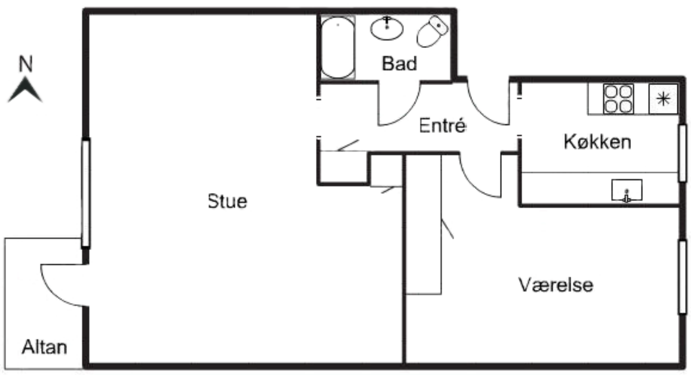
The heat supply is either district heating, gas boiler or external air heat pump.

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.

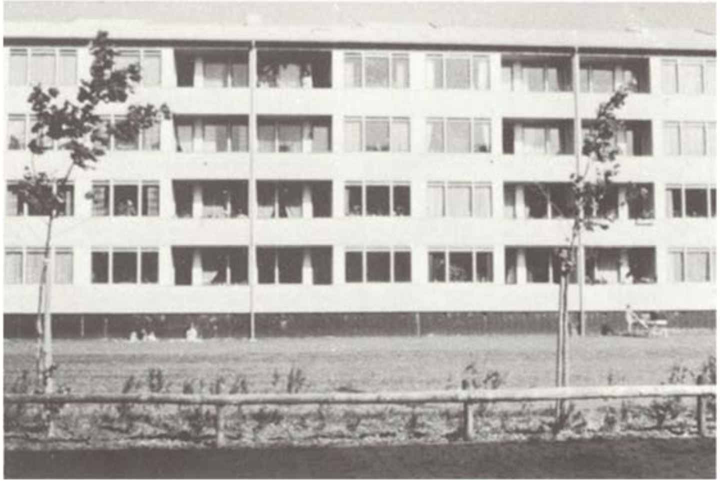
There is an open attic with insulation on the loft. At the starting point there is 95 mm insulation on the loft installed in the late 70's. The external wall is an un-insulated cavity wall with solid brickwork around window and door openings. The basement slap is a wood construction without thermal insulation.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

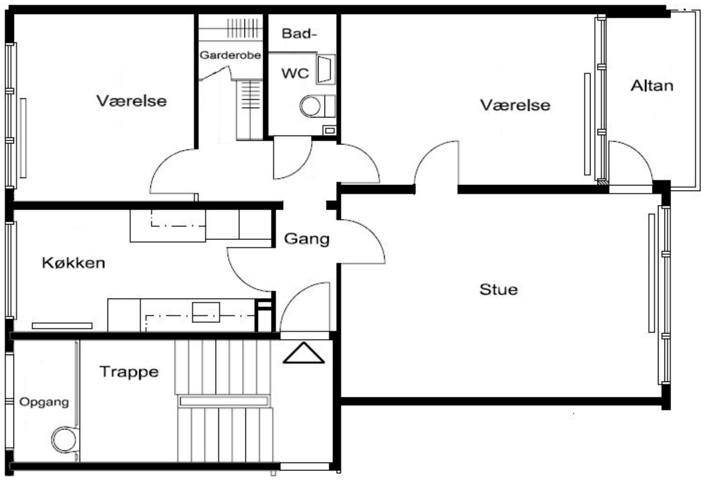
The heat supply is district heating. There are horizontal distribution pipes in the basement and vertical circulation of domestic hot water till the flats on second floor.

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 demand controlled balanced mechanical ventilation with heat recovery in the offices at an average ventilation rate of 1,1 liter/sek. per m² gross floor area. The power needed for air transportation, SEL is 2,1 kJ/m³. The airing windows are automatically controlled with the possibility to open during operation hours and during night time. There is mechanical exhaust from the toilets without heat recovery.

The lighting level is 300 lux in the offices and 100 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 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 according to DS 432.

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 demand controlled balanced mechanical ventilation with heat recovery in the offices at an average ventilation rate of 1,1 liter/sek. per m² gross floor area. The power needed for air transportation, SEL is 2,1 kJ/m³. The airing windows are automatically controlled with the possibility to open during operation hours and during night time. There is mechanical exhaust from the toilets without heat recovery.

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