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ENERGY RENOVATION OF APARTMENT BUILDINGS

ECONOMY AND ASSOCIATED BENEFITS WITH THE ENERGY
RENOVATION OF APARTMENT BUILDINGS TO THE
REQUIREMENTS IN BR15 AND BUILDING CLASS 2020 LEVEL

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Energy renovation of apartment buildings

Economy and associated benefits associated with the energy renovation of apartment buildings to the requirements in BR15 and Building Class 2020 level

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Foreword

This report has been prepared in connection with PSO project 347-027 'Guidelines for the energy renovation of apartment buildings to Low Energy Class 2015 and Building Class 2020'.

The purpose of this report is to inspire Danish housing companies, building owners and managers to undertake the deep energy renovation of apartment buildings. The report covers the optimisation of economy and energy savings associated with the renovation of apartment buildings to a low energy level. Two specific renovation examples are used as a basis: Traneparken in Hvalsø and Sems Have in Roskilde where renovation has principally been carried out in two different ways: Traneparken with external retrospective insulation to almost BR15 level, and Sems Have with an entirely new building envelope to Building Class 2020 level. Both developments involved the retrospective insulation of the building envelope, new windows, new ventilation systems and PV systems.

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Introduction

The energy renovation of an existing residential property can improve the comfort of its occupants considerably in the form of warmer walls, elimination of draughts, cleaner air, reduced risk of mould and less noise. At the same time, energy renovation contributes towards reducing the climatic impact associated with heating homes. However, it will be necessary to reduce energy consumption in the existing building stock by 50% on average to achieve the Danish government's goal of a fossil-free society by 2050. As this is not possible for many buildings, other buildings must undergo 'deep energy renovation' where possible. A deep energy renovation in this guide is defined as an energy renovation that brings the building down to a calculated energy requirement corresponding to either the Danish Building Regulations 2015 (BR15) requirements for new-builds, or an energy requirement corresponding to Building Class 2020 (BK2020). The calculated energy requirement in both cases is the so-called energy framework, for which primary energy factors are used for both heating and electricity supply.

The purpose of this report is therefore to inspire Danish housing companies, building owners and managers to undertake the deep energy renovation of apartment buildings. The report presents two examples of how deep energy renovations are performed in practice and also provides examples of how different energy saving measures may be compiled to achieve the intended saving and how this affects the overall property expenses.

The preparatory work for this guidance is documented in two independent reports [1] and [2]. The reports present a comprehensive analysis of the two energy renovation projects and the results of the numerous calculations performed using various technology packages to achieve the abovementioned goal of an energy framework corresponding to BR15 or Building Class 2020 level. The guide presents a summary of these two reports, and the results are presented in an overall context with some of the benefits that a deep energy renovation entails besides a reduction in the energy requirement and CO₂ emissions.

Extensive material concerning energy renovation, calculation methods and descriptions of technologies, methods and processes, etc. are already available, e.g. see [3], [4] and [5]. This guide therefore aims to take a wider view and consider energy renovation as part of ordinary renovation work and simultaneously include and highlight some of the numerous other benefits energy renovation brings to create a more coherent and holistic perspective for energy renovation. In an analysis of the energy saving measures and various combinations of these, it is often found that energy renovation in itself is rarely financially attractive and therefore motivating. However, this changes somewhat when the real additional costs of energy renovation are taken into consideration (after the expenses for ordinary renovations have been deducted) in relation to both energy savings and other benefits. From this perspective, additional investments in energy measures can pay dividends.

Summary

Typically, the greatest value of an energy renovation lies not in the energy savings themselves, but in the other improvements that it brings. This typically concerns: better indoor climate in the form of improved thermal comfort, air quality improvements, improved light, less dust and no draughts (thermal downdraught). Additionally, warmer exterior walls and windows give greater scope for more flexible furnishing and therefore in practice an increase in the usable area of the property.

Calculations in this report demonstrate that, when a renovation is to be carried out anyway, it is often not much more expensive to carry out the renovation in accordance with the BR15 requirements than with the Renovation Class 1 requirements, and similarly in accordance with Building Class 2020 (BK2020) compared with BR15.

The economic calculations for various packages of energy measures also clearly show that a deep energy renovation of apartment buildings is normally only performed in connection with scheduled renovations. For example, this could be because of ordinary maintenance, restoration, modernisation or improvement of the indoor climate – typically as part of the implementation of a comprehensive plan, including those receiving grants from the National Building Fund (Landsbyggefonden). It is therefore important that renovations that are being carried out now do not prevent deep energy renovations. Examples include window replacements that prevent the economic conditions being appropriate for subsequent façade insulation, or a roof renovation that does not factor in an extension in the roof overhang to allow for exterior façade insulation at a later date. Individual renovations being carried out now must therefore be included as part of a long-term plan for renovation.

It is important:

- that building owners and consultants base their work on the specific building in question to determine energy renovation measures that make sense.
- to note that the use of renewable energy, and thus the effect on the building's energy requirements, is strongly dependent on the billing method used.
- that calculations of the anticipated energy savings are performed using a standardised method, e.g. as referred to in 'Industry guidance for energy calculations' [6]. Alternatively, a new online tool called BeReal [5] may be used to determine a realistic energy consumption.
- that all energy consumption is included in the calculations, as the expected energy consumption following the renovation will otherwise be based on an incorrect basis.
- that the renovation process itself is planned carefully to create a high-quality and complete overview of all phases of the project. This ensures knowledge sharing and optimisation of the methods in each phase in relation to the overall process for both the construction client and consultant. This is described in more detail in SBi Instruction 269 'Energy renovation of large buildings - method and process' [4].
- that residents are involved (see Annex A) and user guidance is prepared for their property following renovation.
- that the development has an energy administrator to monitor energy consumption and ensure the commissioning of installations, etc. following the renovation for optimal operation of the development.
- that the building is considered in the context of the entirety in which it is situated. What are the existing supplies like and what are the future plans for these? Perhaps the goal of a CO₂-neutral supply may be achieved in just a few years, and energy and CO₂ reductions will come second in relation to improvements to the indoor climate of the properties.

Clear advantages of low energy renovation

The value of non-energy-related improvements associated with energy renovation

The greatest value of energy renovations often lies not in the energy savings themselves, but in the other improvements that they bring. This typically concerns: better indoor climate in the form of improved thermal comfort, air quality improvements, improved light, less dust and no draughts (thermal downdraught). Additionally, warmer exterior walls and windows give greater scope for more flexible furnishing and therefore in practice an increase in the usable area of the property.

Comprehensive documentation has been prepared for so-called 'co-benefits' [7] in connection with an international cooperation project under the direction of the International Energy Agency (IEA). The benefits are divided into two categories: Private and community. 'Private' refers to individual residents and 'community' refers to factors such as public health, employment, climatic impact and increased productivity. In this context, the private category is further divided into improvements primarily relating to residents and improvements primarily relating to housing companies.

Benefits for residents and housing companies

Benefits experienced by individual residents are in turn divided into three types of non-energy related improvements: Building quality, direct economic benefits and user comfort. The fact box includes the most important co-benefits identified for each of these categories.

Fact box – Private benefits (co-benefits)	
Building quality:	Warmer surfaces and no thermal downdraught allows entire building area to be furnished. Less external noise.
Direct economy:	Reduced energy costs and much less vulnerability in relation to fluctuating energy prices.
User comfort:	Improved thermal comfort directly improves well-being and in this context: Fewer sick days. Improved air quality benefits everyone but is particularly important for allergy sufferers, for whom cleaner air with reduced particles and pollen and less dust (remember to replace filters) can be of essentially invaluable importance.

Fact box – Benefits for housing companies (co-benefits)	
Building quality:	Reduced problems with condensation, moisture and mould and mildew formation and thus reduced building maintenance. More attractive housing, both for private accommodation owners and rental properties. The improvements can also increase the variety and identity of a residential neighbourhood. Gives the housing company a greener profile.
Direct economy:	Buildings are an important asset to housing companies and constitute capital that must be maintained to retain their value and provide return in the form of the potential for continuous use or the continued letting of the building. Fewer vacant properties improves the economics of the section. Reduced energy costs and much less vulnerability in relation to fluctuating energy prices. The energy investment will lead to lower operating expenses, e.g. in connection with the replacement of wooden windows with composite wooden aluminium windows.

Community benefits

Community benefits may correspondingly be categorised into two main areas: Environmental and economic. The primary non-energy-related benefits of an energy renovation are summarised in the fact box.

Fact box – Community benefits (co-benefits)	
Environmental:	<p>Reduced pollution resulting from reduced energy consumption. This is of direct importance for the health of the population and reduces the number of buildings damaged by air pollution.</p> <p>Reduced climatic impact in the form of reduced CO₂ discharge.</p> <p>A significant reduction in material consumption and thus a reduction in the climatic impact associated with the production of such materials is achieved if energy renovation is chosen over demolition and the construction of a new building</p>
Economic:	<p>Fewer sick days primarily resulting from reduced air pollution both indoors and outdoors and as a result of the improved indoor climate.</p> <p>Increased productivity and more effective learning due to the combination of improved thermal comfort and improved air quality in the home.</p> <p>Increased employment in connection with execution of renovation projects.</p>

Economic value of non energy-related improvements

For residential construction, improved insulation of the exterior walls and better windows means that residents can furnish and use the entire area of the apartment. It was not possible to have furniture against external walls because of the risk of mould prior to renovation and similarly sitting close to the windows was impossible because of thermal draught. The value of the increased usable area following renovation can be estimated as the value of half metre-wide strip along each of the façades. This corresponds to an area of around 9 m² for an average-sized apartment, which with a typical rent of DKK 1 200/m²/year will therefore have a value of around DKK 10 000 per year per apartment.

It is harder to put a value on fewer problems with moisture, mould and mildew. However, any building owners, both private individuals and housing companies, that have experienced mould will be aware of the cost of removing this.

The value of the reduced pollution and thus the reduced number of patients with respiratory diseases is also significant, but difficult to quantify.

It is even harder to quantify the values of the reduced CO₂ emissions. However, there is no doubt that limiting this is of great value, because climate change stems from the increase in CO₂ concentrations in the atmosphere.

This is also emphasised by the Paris Agreement between the Member States of the United Nations Framework Convention on Climate Change to limit CO₂.

An overall societal perspective should be that the value of all of the community non-energy-related benefits should be recognised and turned into grants for energy improvements. The Rocky Mountain Institute in the USA has prepared interesting and inspiring guidance enabling people to calculate and document the economic value of 'deep energy renovation'. The guidance can be downloaded free of charge on the institute's website [8].

It is easy to conceive energy saving as a co-benefit if a decision is made to 'go all the way' in the valuation of the non-energy-related improvements and the optimisation of building improvements based on such a valuation!

Two examples of completed energy renovations

Two specific renovations have been used as a starting point: Traneparken in Hvalsø and Sems Have in Roskilde where renovation has principally been performed in two different ways: Traneparken with external retrospective insulation almost to BR15 level and Sems Have with an entirely new building envelope to Building Class 2020 level. Both developments received new ventilation systems, PV systems and improved daylight utilisation.

The developments formed the basis for the report, in which various renovation measures extending beyond the measures selected for the two developments are analysed. An apartment building in Traneparken is used as a starting point and the building has been used as a reference building in the theoretical analyses. The reference building has been used to analyse different renovation packages to achieve an energy requirement fulfilling the energy requirements for Renovation Class 1, BR15 and Building Class 2020 for a typical apartment building. The calibrated model therefore corresponds to the apartment block in Traneparken before the building was renovated. The calibrated model can be both scaled up and scaled down, thus enabling various conditions to be changed, thereby giving the project a broad application.

The benefit of using two renovations that have been realised is that the results are not merely hypothetical or theoretical but have actually been carried out in reality.

Example: Traneparken



Traneparken before the renovation.

Traneparken comprises three apartment buildings, each three storeys high with a total of 66 apartments. These are typical examples of Danish apartment buildings from the 1960s with prefabricated concrete sandwich elements with relatively poor insulation. The buildings were run-down and uninspiring in appearance. There were problems with the façades, windows and roofs, etc. The energy requirement was high and the indoor climate was poor. The buildings required complete renovation.

The primary goal of the renovation was to improve the concrete walls, which were run-down, but it was also a desire to:

- Renovate other run-down parts of the buildings
- Improve the indoor climate
- Reduce the energy consumption
- Add balconies to all the apartments
- Improve the surrounding outdoor green spaces.

The objective was that the development should fulfil low energy class 2015, see BR10.

The roofs and exterior walls of the building were retrospectively insulated and a new façade and new windows were installed. The old extraction system was replaced with an energy efficient balanced mechanical ventilation system with heat recovery. The additional insulation and new ventilation system have improved the indoor climate and air quality of the apartments. The warmer walls and windows make it easier and more pleasant to use the entire floor area of the apartments. All apartments have been given a balcony with a view over the renovated green areas surrounding the buildings. A PV system on the roof of one of the buildings helps reduce the energy requirement for the common laundry facilities and the new ventilation system. Heat consumption has been cut by around 33% if the before and after measurements for heating and hot water consumption are compared directly.

The total energy requirement of the buildings after the renovation, i.e. the total heat requirement plus electricity requirements for building operation is 70.7 kWh/m², giving the building a B rating. In the latest version of the building regulations, 50% of the basement area can be included in the energy framework, thus resulting in an energy requirement of around 48.1 kWh/m². This corresponds to Renovation Class 1 or an A2010 energy rating.

The reason that the development does not comply with the requirements of BR15 is primarily because there are relatively large heat losses from uninsulated pipes in both the heat distribution system and the hot water installation in the basement and in connection with distribution to the apartments. If these pipes were retrospectively insulated with e.g. 50 mm insulation and 75 m² PV cells were also installed, the development would comply with the BR15 requirement.

Traneparken required more extensive renovation because of the run-down façades, roof structures and windows. This renovation requirement meant it was also decided to perform a deep energy renovation of the development at the same time. Because of this, Traneparken has simultaneously achieved greater energy savings, the residents have got aesthetically more attractive buildings, a significantly improved indoor climate, greater usable area of the apartments, balconies and significantly improved building surroundings.



Traneparken after the renovation.

Example: Sems Have



Sems Have before the renovation.

The Sems Have development was originally built in 1970-72 under the name of Ungdommens Hus. The buildings then housed a nursery, kindergarten, youth club, college and two halls. Amongst other things, the basement contained a meeting room for associations. Difficulties in leasing the buildings began to emerge by as early as the 1980s. In 2011, Roskilde Municipality terminated the lease for the nursery, kindergarten and youth club.

Boligselskabet Sjælland was therefore left with some very specially decorated buildings that could no longer be leased for their original purpose. The buildings were also very run-down and in need of renovation, despite the fact that the façade had been renovated in 1995, involving the retrospective installation of insulation and new windows.

When the decision to renovate was taken, Boligselskabet Sjælland required all new-builds as a minimum to be built to the standard Low Energy Class 2015 (now BR15). This was therefore also the objective for the renovation of Sems Have. However, when it became apparent that an upgrade from Low Energy Class 2015 to Building Class 2020 (for calculation purposes) would only require a modest amount of additional investment, it was decided to aim for the energy requirements for Building Class 2020 (BK2020). The basements were not directly included in the renovation contract because of uncertainty regarding the future use of these. The energy calculations were therefore performed excluding the basements.

Sems Have is located in an area of apartment buildings comprising smaller apartments. Boligselskabet Sjælland therefore wished to construct a number of larger apartments in the area, as there is strong demand for such apartments in Roskilde. Additionally, the complete renovation of the two buildings could help give the area an architectural boost. The buildings and apartments appear neat and contemporary following renovation. The apartments have been easy to let, as there is a waiting list for apartments at Sems Have. The rent, excluding consumption costs per m², is in line with similar apartments in Roskilde. At the same time, heating bills are considerably lower than in other similar developments. The building renovation was particularly deep, as only the load-bearing structures and gables in Blok A were retained. The technical installations were also replaced, as the pipe and cable conduits were unsuitable for the new modern apartments. The deep renovation meant that lead paint, asbestos and PCBs had to be removed and sent to landfill. The old modular measurements were also a challenge for fitting out the new apartments. The fact that the basements were not directly included in the contract also presented challenges. This led to additional expenses because technical installations in the basements had to be adapted later.

The electricity consumption recorded for operating the buildings is very similar to that calculated for actual use of the buildings. The electricity generation of the PV cells is slightly higher than expected, while the heating requirement is 150% higher than calculated using the Be15 conditions [9].

The parameter variations of Be15 indicate that the increased heating requirement is due to other uses of the building (higher room temperatures, increased ventilation and greater infiltration losses), and because heat losses from the ventilation system and heating pipes in the basement were not included in the original energy calculations.

The gross energy requirement calculated in accordance with BR15 is due to the additional heat loss of 28 kWh/m² per year, which is somewhat higher than the requirement for BK2020 of 20 kWh/m² per year. In future projects, it will therefore be important to ensure that all energy consumption is included in the calculations during the planning phase.

It is difficult to assess the energy saving that the renovation has led to because the use of the buildings has changed. The energy consumption has been reduced by around 50% if the before and after calculations are compared directly. Although the goal of reducing the energy requirement to BK2020 was not met, there has still been a considerable reduction in the energy consumption both compared with before the renovation and in relation to similar Danish apartment buildings.



Sems Have after the renovation.

How can a low energy status be achieved in connection with the renovation of an apartment building?

Energy renovation in this report refers to the renovation of an apartment building with the objective of reducing the calculated energy requirement to a specific energy class: Renovation Class 2, Renovation Class 1 (=BR10), Building Regulations 2015 (BR15) or Building Class 2020 (BK2020). It is not relevant to include Renovation Class 2 in this report because renovations to Renovation Class 2 are not normally considered to be 'deep'. The energy requirement is calculated as the so-called 'energy framework', which is often calculated using the program Be15 (calculation of energy requirement) [9], but may also be calculated using other programs calculating 'in the same way' as Be15. The calculations for energy savings and economy for this guide have been performed using the calculation program ASCOT [10], which calculates both the energy savings and economy in the same calculation.

Fact box – Building regulation requirements for energy framework requirements

For housing, colleges, hotels and similar buildings, the total demand for energy supply for heating, ventilation, cooling and hot water per m² of heated floor area must not exceed:

Renovation Class 2	110.0	+	3200/A	kWh/m ²
Renovation Class 1	52.5	+	1600/A	kWh/m ²
BR15	30.0	+	1000/A	kWh/m ²
BK2020	20.0			kWh/m ²

In the calculated energy requirement, the 'energy framework' must adhere to the primary energy factors used for heating and electricity supply. In particular, the electricity contribution from PV cells can only be included in the energy framework with up to 10 kWh/m²/year (prior to multiplication by the primary energy factor). Please refer to the building regulations for more detailed information on the calculations.

Fact box – Primary energy factors

	District heating	Electricity
Renovation Class 2	1.0	2.5
Renovation Class 1	1.0	2.5
BR15	0.8	2.5
BK2020	0.6	1.8

'Scheduled renovation – scheduled renovation'

The introduction mentioned that a deep energy renovation normally always covers scheduled renovations, corresponding to the ordinary renovation and maintenance of the building. Two sets of calculations have been prepared for the package of energy measures analysed to illustrate the importance of this. One set covers the full price of the renovation and the other set deducts the price of three renovation measures from the total price that would have been performed in any case. This concerns the measures:

- 1 Renovation of the exterior walls (including scaffolding costs)
- 2 Window replacement
- 3 Installation of mechanical ventilation with heat recovery.

The reason that the installation of mechanical ventilation with heat recovery is included as a single measure that would have been performed in any case is partly because extraction ventilation systems often cause problems with draughts, and partly because many apartment buildings experience problems with mould because of inadequate ventilation, particularly following window replacement, which makes the building more airtight than before. These three renovation measures are referred to as 'scheduled renovation' in the following section.

Reference development

As described in the previous section, an apartment block in Traneparken has been selected as a reference building for the calculations. The building had a calculated energy framework of 135.5 kWh/m²/year. The three floors have a heated floor area of 1 808 m² and contain 18 apartments. The built-up area is approximately 604 m². The window area represents 17% of the floor area, with half of the windows facing south and the other half facing north. The building is classified as medium heavy and the hot water consumption is estimated to be 250 l/m² per year. The building is ventilated with year-round extraction ventilation at 0.34 l/s/m² and an SEL value of 1.0 kJ/m³. The basement is unheated and there are relatively high heat losses from the heat distribution pipes of around 40 kWh/m²/year.

Table 1. Building envelope. Reference building before the renovation.

Construction	U-value [W/m ² K]	G-value [-]	Area [m ²]
Windows/doors	1.80	0.67	315.4
Exterior walls	0.67		898.4
Basement exterior walls	0.93		276.7
Roof	0.20		603.7
Floor to basement	0.66		603.7
Basement floor	0.40		573.2
Thermal bridges	ψ value [W/mK]		Length [m]
Linear thermal transmittance, foundations	0.40		132.0
Linear thermal transmittance, windows	0.08		674.0

The windows in the reference building have already been replaced once since the building was first constructed with windows with a U-value of 1.8 W/m²K. A basic calculation has been performed where the windows have a U-value of 2.9 W/m²K, corresponding to the original windows. This increases the energy framework of the reference building by 19 kWh/m²/year, which can therefore be added to the energy framework calculation before the energy renovation in order to compare the results with the current building, which has windows with a higher U-value. The energy saving associated with the window replacement thus increases by 19 kWh/m²/year. The less efficient windows would have resulted in a starting point for the renovation of 154 kWh/m², instead of 135.5 kWh/m² per year.

Energy renovation measures

Four energy technology 'packages' per scenario have been compiled in order to reduce the primary energy requirement in the calculations to correspond to the three energy frameworks referred to. Renovation Class 1 (BR2010), BR2015 and Building Class 2020 (BK2020).

The four technology packages have been chosen so that they illustrate some of the many ways in which it is possible to achieve the desired energy level. At the same time, these also indicate how much the economy in the form of investment per apartment and total energy costs per m² can vary depending on the 'package' selected. Calculations are based on the following energy saving technologies:

- Exterior wall insulation
- Loft insulation
- Basement wall insulation
- Insulation of unheated basement
- Reduced heat losses from installations
- Low energy windows
- Ventilation with heat recovery
- Solar heating
- PV cells*, small units of up to 1.0 kWp per apartment
- PV cells*, large units of around 4.8 kWp per apartment.

* covers only electricity requirement for building operation.

** covers both electricity requirement for building operation and in properties. This is a hypothetical example illustrating the importance of a large PV installation for the overall energy saving if net billing is reintroduced, i.e. as is popularly described, i.e. when the meter 'runs backwards' when electricity is sold to the grid. This calculation does not include the limitation of PV power normally applicable to energy framework calculations.

The requisite input data for the calculations has been obtained for each technology, primarily consisting of technical data for performance and investment prices - see Annex A in the report on the energy renovation of Traneparken [2].

An individual calculation of energy savings and economy (present value and simple payback time) has been made for each technology before looking at package solutions - where applicable, see Annex B in the report on the energy renovation of Traneparken [2]. These calculations include three alternatives for the PV cell calculations:

- PV cells - small systems of 0.47 kWp per apartment - only covers the electricity requirement for building operation with hourly billing, i.e. a large proportion of the electricity generated must be sold to the grid.
- PV cells - small systems of 0.47 kWp per apartment - only covers the electricity requirement for building operation with net billing, i.e. all electricity is calculated at full price.
- PV cells - large systems covering both the electricity requirement for building operation and in the properties, see more detailed description above under **.

The three different calculations for PV cells are performed because of the low payment currently achievable for PV electricity sold to the electricity grid. Based on this, it is interesting to illustrate the economics for the installation of PV cells in situations where net billing is not possible and situations where it is possible. This is illustrated by the first two calculations. The economics change markedly if the electricity can also be used for individual consumption in apartments besides building operation if this is concurrent with net billing. The latter option requires tenants to revoke their right to choose their own electricity supplier.

Results of the calculations

The results of the numerous calculations are summarised in three tables in this section. Table 2 shows the interval between both the lowest (min.) and the highest (max.) investment per apartment for the four technology packages calculated, and Table 3 and Table 4 show the total energy costs per m² for two of the situations utilising PV electricity described above. All three tables show the figures for both cases where renovation is scheduled and cases where it is not. In addition to the investment and energy costs, the calculation results also cover the repayment time and the present value. However, the repayment period and the present value cannot immediately be linked

to the property expenses in the same way as the total energy costs. The total energy costs are calculated based on the borrowing costs for energy investments, the resulting energy consumption and the expenses for the operation and maintenance of the energy technologies.

Table 2 shows the investment required per apartment - in this case calculated for an area of 79 m², corresponding to the average size of a Danish apartment in the public sector. The table primarily illustrates the difference in the magnitude of the investment for situations where renovation/maintenance must be performed in advance and situations where this is not the case. It shows that in cases where no renovation in advance is to be carried out, the investment in the energy renovation will cost DKK 125 000 more per apartment than in the case of scheduled renovation. This highlights the importance of considering energy renovation in renovation/maintenance work that is already scheduled, where it is possible to renovate to Building Class 2020 for an additional cost of between DKK 58 000 and DKK 79 000 per apartment.

Table 2. Investment in DKK per apartment to achieve various energy classes in the two situations of scheduled renovation and situations where this is not the case. 'Min.' in the table refers to the cheapest renovation package and 'max.' refers to the most expensive.

					Energy saving = reduction of energy framework, kWh/m ² /year	
	In connection with scheduled renovation		Not in connection with scheduled renovation		U-value of reference window = 1.8 W/m ² K	U-value of reference window = 2.9 W/m ² K
	min. [DKK]	max. [DKK]	min. [DKK]	max. [DKK]		
BR10	33,000	74,000	158,000	199,000	82	101
BR15	45,000	71,000	170,000	196,000	105	124
BK2020	58,000	79,000	183,000	205,000	115	134

Table 2 also shows that the difference in the amount required to achieve BR15 and BK2020 is not large. The table also shows that the most expensive technology package implemented to achieve BR10 is more expensive than the package used to achieve BR15 when the 'scheduled renovation' expenses are deducted. The primary reason for this is that the BR15 package includes PV cells, but the packages are otherwise quite different. In the case of scheduled renovation, the additional costs of achieving BK2020 instead of BR10 is just under 30%, while the costs are around 9% in the second case. The corresponding figures for achieving BR15 is just under 10% and 2.5%.

Table 3 and Table 4 show the total energy costs before and after the renovation. The total energy costs before the renovation contains only costs for energy consumption. The total energy costs following renovation contain both energy and investment costs in addition to expenses for the operation and maintenance of the new energy measures.

For the results in Table 3, it is assumed that the PV electricity generated is only used for operation of the building, but as consumption and generation often do not occur at the same time, a high proportion of the PV electricity must be sold to the grid for a low price.

Table 3. Total energy costs in DKK per m² per year for PV electricity used for the operation of the building.

	In connection with scheduled renovation		Not in connection with scheduled renovation	
	min.	max.	min.	max.
Before	71	71	71	71
BR10	59	94	162	197
BR15	69	83	172	186
BK2020	72	89	175	192

Table 3 shows that for the scheduled renovation of the building, it may be energy renovated to BK2020 with essentially unchanged total energy costs with the cheapest (min.) package of energy renovation measures and for an increase of these costs by DKK 18/m²/year for the most expensive (max.) package. In a situation where the building will not be renovated in advance, the total energy costs rise by DKK 104-121/m²/year when renovating to 2020 level. This must be considered in relation to a typical rent of DKK 900-1 000/m²/year.

The hypothetical situation in Table 4 assumes that the PV electricity can also be used for household electricity concurrently with net billing. All of the electricity generated may therefore be used in the building. Note that the 'before' energy costs in Table 3 therefore include the expenses for household electricity in the apartments.

Table 4. Total energy costs in DKK per m² per year for PV electricity used both for the operation of the building and household electricity. PV cells are only included in the calculations for BR15 and BK2020. BR10 is therefore not included in Table 4.

	In connection with scheduled renovation		Not in connection with scheduled renovation	
	min.	max.	min.	max.
Before	159	159	159	159
BR15	108	136	212	239
BK2020	106	133	209	237

If a comparison is made for the before and after situation where all PV electricity can be used in the building for both building operation and household electricity, the total energy costs fall by between DKK 26 and 53/m²/year for renovation to BK2020. Again, there is very little financial difference in renovating to BR15 or to BK2020. One of the reasons for this is that lower primary energy factors are used for both the calculated electricity and heating requirement for BK2020, and thus the additional investment required to achieve this is limited.

If, on the other hand, an energy renovation is not scheduled, the total energy costs increase by DKK 50-78/m²/year when a large proportion of the PV electricity is not sold to the grid for a low price. As is shown in Table 3, the total energy costs also increase by DKK 104-121/m²/year when the PV electricity is sold.

In summary, the three tables show that there is no major difference in energy renovating to Building Class 2020 (BK2020) instead of for the requirements for new builds in BR15, and in several cases, it may be more profitable to choose BR15 or BK2020 over BR10 (Renovation Class 1).

When comparing the results in Table 3 and Table 4, it can clearly be seen that the potential for using PV electricity for household electricity together with the hypothetical potential for net billing throughout the year may result in significant financial savings for residents. This simultaneously results in large electricity savings. However, this must be viewed from a societal perspective which takes account of both how the electricity sent back to the grid may be used in other locations and how the electricity taken from the grid is produced.

As mentioned in the introduction, Annex A of the report on the energy renovation of Traneparken [2] contains the results of all the calculations that have been performed. For example, this includes payback times, present values and the packages of energy saving measures compiled for each calculation. For example, this shows a payback time for both BR15 and BK2020 of 11 and 14 years respectively for scheduled renovations and a payback time of 40-43 years if this is not the case.

Table 5 shows one of the four packages of energy saving measures compiled to achieve one of the three different energy frameworks.

Table 5. Examples of packages of energy saving measures compiled to achieve the three different energy classes.

Energy saving measure	BR10	BR15	BK2020
Exterior wall insulation [mm]	+200	+200	+200
Low energy windows [-]	Triple glazing	Triple glazing	Triple glazing
Heat recovery for ventilation system [%]	90	90	90
Seal of building envelope [l/s m ²]	1,0	1,0	0,5
Reduced heat losses for installations/technical insulation [mm]	+50	+50	+50
Insulation of slab above basement [mm]			+100
Basement wall insulation [mm]	+100		+200
PV cells [kWp/apartment]		0.75	0.60

It can immediately be seen that to reach BK2020 level in relation to BR15 level, basement wall insulation and insulation of the slab against the basement have been included in addition to an improved seal of the building envelope. The same outcome could have been achieved by replacing the insulation against the basement with a solar heating system and an additional 100 mm exterior wall insulation. Further details and the other package solutions may be found in Annex A of the report on the energy renovation of Traneparken [2].

Caution regarding the use of economic results

The economic results presented in this guide must be used with great caution. This is for many reasons. Firstly, there will always be special circumstances for specific projects which mean that the cost of carrying out the various energy saving measures will vary in relation to the prices used in the calculations (primarily Molio Price Data [11]). These must therefore only be used for guidance. It is well known that two quotes provided for the same tender material may vary by a factor of 2. Compared with the renovation costs for Traneparken, these also appear significantly higher, but this may be because a number of repairs to damage on the existing walls had to be made in connection with the insulation of the exterior walls.

The behaviour of users is another key factor for the actual savings achieved. An average temperature of 20°C was used in the calculations as is typical for energy framework calculations. Typical residents may have temperatures of 22-23°C. It might initially be believed that implementing measures to reduce the building's heat loss would mean greater energy savings. However, there may have been a number of residents living with temperatures lower than 20°C prior to renovation in order to save money, but who after renovation used this opportunity to increase their level of comfort without incurring significantly higher costs, thus increasing the temperature by two or three degrees, a phenomenon often referred to as 'prebound' and 'rebound' effects. This means that the measured energy savings will be less than the calculated savings. In return, residents have gained considerably more comfort. It may therefore be difficult to reduce actual energy consumption for heating by more than 50%, even if the energy framework for BR15 or BK2020 has been fulfilled.

Around 90% of all rental properties in the public sector are heated by district heating. The calculations have therefore been made for a building supplied by district heating. Corresponding calculations may naturally be performed if the heat supply is based on oil, gas, heat pumps or biofuels.

Some of these calculations have been performed in another context [12], and this shows that, for a building supplied with heat from a heat pump, the results will correspond to the results for district heating, while the economy for buildings supplied by oil and gas will be significantly better than for district heating and conversely worse if the building is supplied with e.g. wood chips or a wood pellet stove.

Finally, the calculated savings/total energy costs depend on the development of energy prices and interests rates, something which may affect the results significantly in the coming years.

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Annex A. Brochure for residents

This Annex provides suggested content for a short 'brochure' of a maximum of four A5 pages that housing companies may use when contacting residents regarding a planned energy renovation.

The brochure must describe:

- What the renovation will involve
- Why it is being performed
- How will residents benefit, e.g. improved comfort and energy savings.

Page 1: Introduction

The section has been reviewed on [date] by the consulting engineering firm [name]. The outcome of the review is summarised below and forms a basis for a common dialogue concerning the potential of the section regarding improvements relating to energy and comfort in the development.

Comfort:

The energy renovation of your property may significantly improve your level of comfort. This may mean:

- Warmer walls, no thermal draught, potential to place furniture directly against walls
- No draughts
- Cleaner air
- Reduced mould risk
- Less noise.

Helping to make Denmark greener:

An energy renovation contributes towards reducing the climatic impact associated with heating homes. It is necessary to reduce energy consumption in the existing Danish building stock by 50% on average to achieve the Danish government's goal of a fossil-free society by 2050. As this is not possible for many buildings, other buildings, must undergo 'deep energy renovation' where possible.

Page 2: What does an energy renovation involve? (illustrations)

[The list below can be adapted to specific cases]

- Window replacement
- Increased insulation in the façades and in the roof - and possibly also at the foundations or against an unheated basement
- New ventilation system with heat recovery
- PV panels on the roof
- Etc.

Page 3: Why were these measures in particular chosen? (illustrations)

- Indoor climate - increased comfort and non-energy-related benefits
- Reduced energy requirement and energy costs - the anticipated saving on energy bills is:
DKK [xx]/m²/year (or per apartment)
- Environmental impact/climate changes

Page 4:

- Summary of benefits of energy renovation (illustrations)
- Anticipated schedule and process for renovation/renovation process
- Changes in behaviour required, e.g. in connection with ventilation and use of installations

The purpose of this report is therefore to inspire Danish housing companies, building owners and managers to undertake the deep energy renovation of apartment buildings. The report presents two specific examples of deep energy renovations and provides examples of how various energy saving measures can reduce the calculated energy requirement to levels corresponding to the requirements for new builds in the Danish Building Regulations 2015 and Building Class 2020. The calculations indicate that if renovation is scheduled anyway, it is often not much more expensive to energy renovate according to the BR15 or BK2020 requirements.

The report also shows that the great value of an energy renovation lies not only in the energy saving itself, but also in the associated improvements, such as an improved indoor climate in the properties.

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