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Whole Life Carbon Assessment of Renovation

Possibility of Specifying Limit Values for LCA of Renovation Work

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BUILD
RAPPORT

2022:33

WHOLE LIFE CARBON ASSESSMENT OF RENOVATION

Possibility of Specifying Limit Values for LCA of Renovation Work

Written by Alberte Mai Lund, Regitze Kjær Zimmermann, Jesper Kragh, Jørgen Rose, Søren Aggerholm, & Harpa Birgisdóttir

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Contents

SUMMARY

Introduction

When renovating existing buildings, it is important to ensure the continued function and use of the building. In tandem with this, energy efficiency and material choice should be optimised if the renovation is to result in a *de facto* reduction of environmental impact. Consequently, renovation work should always be regarded from a life-cycle perspective, whereimpacts from materials used are factored in. If the renovation does not result in energy savings, the optimisation will purely relate to the choice of materials.

Purpose

As for newbuild, we can specify LCA requirements for renovation work. The purpose of this project is to analyse the possibility of specifying requirements for the environmental impact of renovation work, where both requirement and methodology must be operational and aim to reduce CO_2 emissions. This is done by systematically combining renovation types and limit values, exemplified via collected renovation projects.

As far as possible, future LCA requirements for renovation projects should be formulated in such a way that they promote decisions to renovate in preference to demolition and rebuilding. Further, requirements should regulate material choice for renovation work to ensure that environmental impact from the new building materials will be as low as possible.

Analytical assumptions

Analyses are based on energy requirements in the existing Building Regulations continuing a methodology already familiar to the construction sector. Renovation cases were collected and then subdivided and analysed according to renovation type. The renovation types are based on existing Building Regulations energy requirements and cover *Change of Use*, *Additions*, *Replacing Building Components*, *Conversion,* and *Structural Alterations*. Further, an extra category, *Other Renovation Work*, has been added to cover the whole spectrum.

A total of six different proposals for limit values are specified. Some of these are at building level whereas others are at building component level.
Limits values 1 and 2 are overall measurements, corresponding to requirements for newbuild relative to construction and building component levels, respectively. Limit values 3 and 4 indicate the so-called environmental payback time of the renovation project relative to construction and building components. Limit value 5 is determined based on existing circumstances, whereas limit value 6 is a requirement specifying a comparison of solutions. Advantages and disadvantages of combining types and limit values are outlined in the report.

Abbreviations:

LCA Life-Cycle Assessment
FBK Den frivillige bæredygtighedsklasse (Voluntary sustainability class)
BR18 2018 Building Regulations
kgCO₂eq Unit for measuring environmental impact (kg CO_2 equivalents)
EPD Environmental Product Declaration
EPBT Environmental payback time

Main findings

Findings

A total of twenty-nine renovation cases were collected, all assessed as major renovation projects both in terms of the extent of renovation interventions and overall area. The cases are not, therefore, representative of minor renovation work in single-family housing.

Four case studies under *Change of Use* show great variations in the environmental impact from materials. Insufficient energy data hampers the overall environmental impact assessment. Limit values 1 and 3 are used to assess the cases in the *Change of Use* category.

Four cases include additions, where environmental load from materials used for the addition has a median value of 6.05 kg CO_2eq/m^2/year, in line with environmental impact from newbuild with a median value of 7.07 kg CO_2eq/m^2/year. Limit value 1 was investigated.

A total of twenty-three cases are categorised as *Other Renovation Work* and show considerable variation in environmental load from materials due to the great scope for renovation in this category. There are generally better energy data from cases in the category *Other Renovation Work* with a median value of the overall environmental load of 7.4 kg CO_2eq/m^2/year. For newbuild, the median value is 9.52 kg CO_2eq/m^2/year. Limit values 1 and 3 were investigated.

At building-component level, analyses of *Conversion*, *Replacement of Building Components*, and *Structural Alterations* were based on limit values 2, 4, 5, and 6. This presents a problem of comparing building components with different starting points in relation to energy status.

Recommendations

Based on project findings, we recommend that future renovation requirements be closely related to the energy requirements in BR18, formulated along the lines of three overall proposals for requirements:

1. LCA requirements for renovation work

For all renovation work over 1,000 m^2, a limit value could be observed at either building or building-component level. A further requirement for all renovation work below 1,000 m^2 could be to make a calculation at either construction or building-component level with no additional requirement to observe limit values. Complying with the requirements at building and building-component level could be effectuated by observing limit values 1 (measurement applicable to the whole building) and 5 (LCA reference as a benchmark of renovation work).

2. LCA requirements for additions

Requirements for *Additions* could be identical to those for newbuild. Initially, this could apply to additions over 1,000 m^2. Alternatively, requirements could be set for additions down to 500 m^2.

3. Special LCA requirements for deep renovation work

In buildings (over 1,000 m^2) undergoing deep renovation work, there could be a requirement that an LCA be made at building level.

Further, we recommend that the data set for a future limit value be extended and that suitable renovation categories determined.

Foreword

The construction sector is responsible for 39% of global emissions of greenhouse gases and to meet our climate targets in 2030, we need to address, in addition to limit values for newbuild, how to implement requirements for the renovation of the existing building mass.

Increased focus on the environmental impact and resource consumption by the building sector resulted in a political agreement on a national strategy for sustainable construction ratified on 5 March 2021. This strategy aims to underpin the building sector's changeover to sustainable construction. The strategy comprises 21 concrete initiatives, including initiative 1 concerning a stepwise phasing in and tightening of CO_2 requirements to newbuild towards 2030 and initiative 13 on overall evaluations of renovation, underpinning the need for decisions on whether to demolish or renovate to reflect the correct balance between various parameters such as economy, quality, and environmental impact.
The political agreement notes that the initiative on overall evaluations on renovation should be applied with the aim of specifying requirements for environmental impact from building renovation. In tandem with this project which focuses on presenting possible methods to set climate targets for renovation, a project on overall renovation assessment has been started by BUILD.

BUILD – Department of the Built Environment, Aalborg University Copenhagen, Division of Sustainability, Energy Efficiency, and Indoor Climate.

Tine Steen Larsen
Divisional Head

1 Introduction

1.1 Background

Today, the construction sector is responsible for 39% of global carbon emissions, of which 28% come from the operational energy used by our buildings and 11% from building materials. The need for more buildings is set to rise proportionally with the population growth. The construction sector will therefore play a major role in reducing carbon emissions in the buildings of the future (World Green Building Council, 2019).

At a European level, the focus of attention is how to reduce environmental load from buildings via different initiatives, including regulation. The European Commission has introduced Level(s), a joint European reporting method for sustainable construction, which includes requirements for calculating LCAs of both newbuild and renovation projects (European Commission, 2018). However, Level(s) leaves the methodology sufficiently open without specifying a set procedure for conducting LCAs, which applies to both newbuild and renovation. The Buildings Directive, which has played a significant role in reducing energy consumption in buildings is being revised (European Commission, 2021). There are proposals to introduce requirements for conducting LCAs for buildings larger than 2,000 m² from 2027 and for all buildings from 2030. However, this will only apply to buildings covered by the Buildings Directive. A few pioneering countries, including The Netherlands, France, Finland, Sweden, and Denmark, have already implemented, or are preparing, environmental requirements using life-cycle assessments (LCAs) for construction, initially mainly for newbuild.

Via the Climate Act, Denmark is set to be a pioneering country in the international effort to reduce global greenhouse-gas emissions, and Denmark has committed herself to reducing emissions by 70% in 2030 relative to 1990 figures. Denmark's goal is to be climate neutral by 2050 (Danish Ministry of Climate, Energy, and Utilities, 2021). To achieve this ambitious goal, the government published, for the first time, a new national strategy for sustainable construction in April 2021 to function as a sectorial plan of action for the building and construction sector (Ministry for the Interior and Housing, 2021). Part of this sustainable strategy involves introducing limit values for the environmental impact of newbuild to the Building Regulations as from 2023. This will mean that, from January 2023, conducting a life-cycle assessment (LCA) of all newbuild is a requirement, and that buildings over 1,000 m² must comply with a limit of 12 kg CO_2/m²/year for environmental impact from operational energy use and materials. Moreover, a low-emission class was introduced: a voluntary low-emission CO_2 class with a limit value of 8 kg CO_2/m^2/year. From 2023, this limit value will be part of a gradual tightening of CO_2 requirements, where, so far, the expected tightening of limit values for 2025, 2027, and 2029 have been introduced. The strategy also includes a desire to prepare a method and a benchmark, so that, in the long term, environmental requirements for construction will also comprise renovation and conversion.

In Denmark, experience of using LCA in construction has primarily come from voluntary certification of sustainable buildings via the DGNB scheme since 2012. During the ten years of DGNB certification, 167 newbuild projects were certified against only 7 renovation projects (DK-GBC, 2022). A total comparable data set for environmental load from newbuild was set up with the publication of the report *Whole Life Carbon Assessment of 60 Buildings – Possibilities to Develop Benchmark Values for LCA of Buildings* (BUILD AAU, 2020). This included data from around 40 DGNB-certified building case studies.

Few reports with LCA of Danish renovation projects exist. Examples include *Livscyklusvurdering af større bygningsrenoveringer (Life-Cycle Assessment of Major Structural Renovation Projects*) (Nygaard Rasmussen & Birgisdóttir, 2015), *Analyse af CO_2-udledning og totaløkonomi i renovering og nybyg (CO_2 Emissions and Overall Economy in Renovations and Newbuild: an Analysis)* (Rambøll, 2020), and *Klimaeffektiv renovering, balancen mellem energibesparelse og materialepåvirkninger i bygningsrenovering (Energy Efficient Renovation, the Balance Between Energy Efficiency and Material Impact from Structural Renovation)* (BUILD AAU, 2021a). The ongoing test phase of the voluntary sustainability class (FBK) will provide additional knowledge about LCA in Danish construction. In September 2022, there were a total of 58 registered projects, of which 8 were renovation projects (Danish Housing and Planning Authority, 2022).

With the present Building Regulation requirements for renovations, focus is on renovating from an operational energy perspective, where the set target for energy retrofitting is based on the economic viability of saving energy. Future climate targets for newbuild cannot readily be transposed to renovations, but as part of the national strategy for sustainable construction it is imperative to carry out a detailed analysis to discover how a benchmark or limit value could also apply to renovations.

1.2 Renovation potential

To realise the contribution made by the existing building mass to lower CO_2 emissions, the European Commission launched the initiative *A Renovation Wave for Europe* (European Commission, 2020), promoting more and deeper energy retrofitting, a life-cycle approach, and converting to renewable forms of energy. If energy retrofitting is to result in concrete CO_2 reductions, renovations must be viewed in a life-cycle perspective, where impact from the materials used to achieve the energy savings are factored in.

Material consumption

There is a great potential in the existing building mass for preservation and renovation to meet future needs. So far, no data exist on the extent of embedded CO_2 in Danish buildings, but a recent study on the overall assessment of renovation show a tendency to greater environmental potential in extensive renovation of large buildings rather than demolishing existing buildings and rebuild (BUILD AAU, 2022). However, it is of decisive importance at which point in the lifetime of a building emissions occur. Figure 1a, outlining the calculation for an extensive renovation of a multi-storey housing project, and Figure 1b, outlining the transformation of a major office building, present the aggregate environmental load over a period of 50 years for operational energy and material consumption in a renovation scenario (brown curve) and in a newbuild scenario for a similar building (black curve).

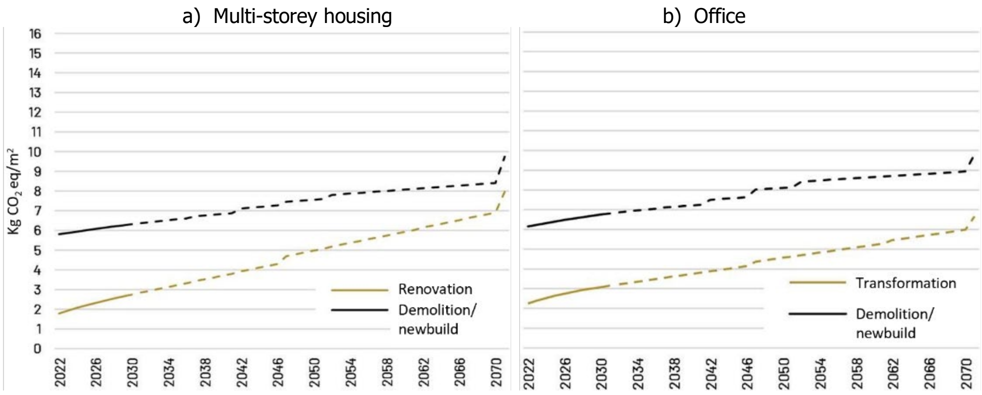


Figure 1 Aggregated environmental load over a period of 50 years for a renovation scenario and a newbuild scenario for a similar building of (a) multi-storey housing and (b) an office building.

It is evident from both graphs that renovation will result in lower climate impact than demolition and newbuild. The study also includes a similar calculation for renovation of a single-family dwelling, however, indicating that in 50 years' time, the renovation will result in higher environmental load due to increased energy consumption (BUILD AAU, 2022).

When renovating existing buildings, it is essential to optimise the building to future-proof both its function and usage, while also keeping operational energy use low. In this way, the lifetime of existing buildings can be extended. Moreover, It is important that material choices are made from an environmental perspective, keeping focus on if and how environmental load can be reduced from the materials in specific renovation projects.

Reducing operational energy use

The potential for reducing operational energy use is primarily an issue in the older building mass. Approx. 70% of the total heated floor space was built before 1979, where energy requirements for all new heated buildings were introduced. If the existing building mass is energy-optimised by an energy retrofit of the building envelope to match levels required in BR18 for conversion projects, consumption may potentially be reduced by approx. 10,100 GWh/year, corresponding to 20% of the operational energy consumption of the total building mass (BUILD AAU, 2021c). The calculation takes into account the fact that an energy retrofit often results in an indoor temperature rise of a couple of degrees, thus reducing the optimisation potential. BR18 requirement targets will mean major and ambitious re-insulation of most buildings of a certain age.

1.3 Extent of renovation in Denmark

To conceptualise the extent and type of renovations generally carried out in Denmark, a review has been made of the most recently collected data. This review is based on the report *Analyse af efterlevelse af bygningsreglementets energikrav ved renovering af eksisterende bygninger samt omfanget af renovering (Analysis of Compliance with Building Regulation Energy Requirements for Renovation of Existing Buildings and the Extent of Renovation Work),* mapping the extent and renovation types during the period 2019–2020 from quantitative interviews (Viegand Maagøe A/S & Wilke A/S, 2021). Respondents range from private houseowners, property administrators, municipalities, contractors, and consultants. Based on survey responses and data extraction from the Building and Housing Register, a nationwide assessment of the renovation extent was made. Due to variances in questions and responses between the six groups of respondents, it was only possible to include single-family dwellings and multi-storey housing. For single-family dwellings, data were extracted from the Building and Housing Register for small buildings covering farm houses, detached single-family

dwellings, and terraced housing. The total number of small buildings and multi-storey housing used to scale up renovations nationally is listed in Table 1.

Table 1 – No. of small and multi-storey housing extracted from the BBR Building and Housing Register, December 2020

Building type	No. of buildings
Small buildings	1,448,664
Multi-storey housing	94,649

The survey shows that, during the period 2019–2020, 33% of single-family homeowners renovated their houses. This corresponds to 475,450 small buildings in Denmark. Figure 2 shows the 475,450 renovated small buildings subdivided into renovation type. The figure indicates that kitchen and bathroom renovations are the commonest renovation types, totalling 204,239 renovations or 43%.
Window replacements are the commonest form of building envelope renovation, totalling 179,026 or 38%. After this, comes renovation of heating installations, supposedly carried out in 107,674 cases. Renovation of exterior walls and roofs supposedly occur in 20% and 22% of renovations, respectively. This corresponds to 102,604 exterior wall renovations and 95,956 roof renovations of small buildings.

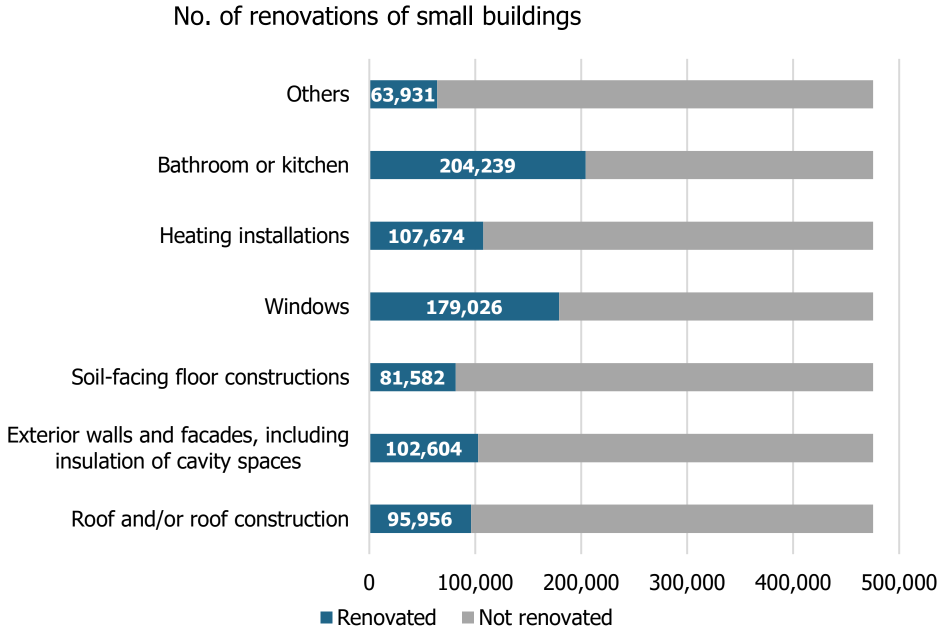


Figure 2 No. of renovations of small buildings calculated according to renovation type based on (Viegand Maagøe A/S & Wilke A/S, 2021) and upscaled to nationwide coverage by using the BBR Building and Housing Register.

In the case of multi-storey housing, respondents reported renovations carried out in 19% of the buildings during the period 2019–2020. This corresponds to a total of 17,610 multi-storey buildings being renovated in Denmark. Figure 3 shows the frequency of renovation interventions for this building type. Once again, inside the building envelope, window replacements are the most frequent renovation type across the seven categories. This is the case in 62% of renovations, corresponding to 10,858 window replacements. After this, come 6,104 cases of roof renovations and 4,484 cases of exterior wall renovations.

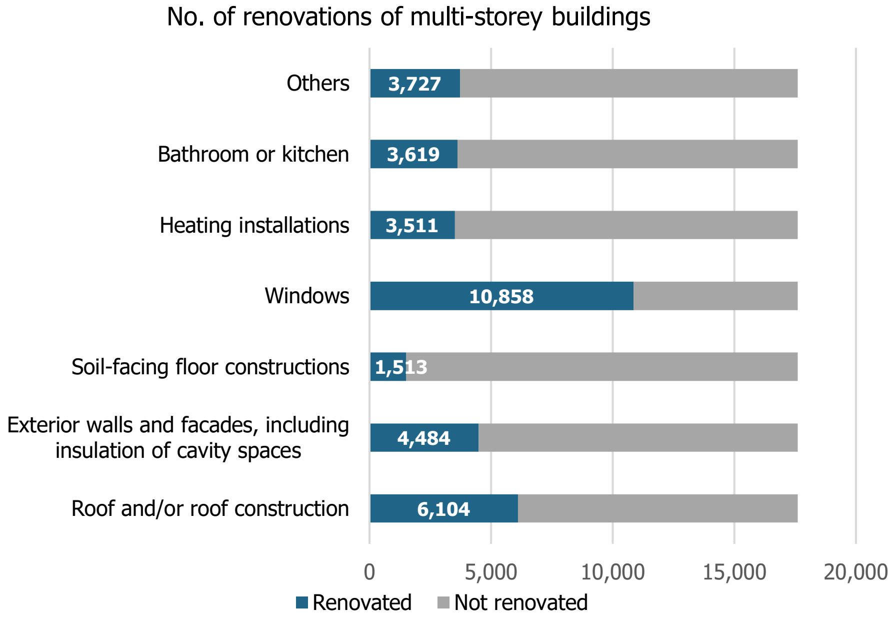


Figure 3 No. of renovations of multi-storey buildings calculated according to renovation type based on (Viegand Maagøe A/S & Wilke A/S, 2021) and upscaled to nationwide coverage by using the Building and Housing Register

1.4 Purpose

This report presents the investigations carried out via the project "Evolving limit values, data collection from buildings, and analyses of the climate and economic effects" carried out during the period September 2021 to September 2022. The purpose of this project was to analyse the possibility of specifying requirements for the environmental impact from renovations, where both the requirement and methodology must be operational and aim for reduced carbon emissions. This is done via a systematic combination of renovation types and limit values, exemplified via collected renovation projects.

The aim is to base the analysis on existing energy-related renovation requirements in the Building Regulations to work with concepts and methodologies already familiar to and well-established in the construction sector.

The project will support the future requirement for LCA and limit values, obligatory for newbuild in the Building Regulations from 2023; moreover, accumulate knowledge and data sets and investigate possibilities for a future environmental target benchmark or limit values for renovation work. The purpose of the requirements will be to support decisions to renovate and so preserve the existing building mass and the CO_2 embedded in the structures. This should be followed by a future requirement to promote renovation solutions that ensure an absolute minimal carbon footprint from building materials used during renovation.

2 LCA of renovation work

Environmental impact of construction projects is calculated via a standardised life-cycle assessment (LCA) in accordance with DS/EN 15978 (Danish Standards, 2012), specifying the construction phases throughout the lifetime of a building. In a long-term perspective, it is possible to include the environmental impact that takes place in the construction phase, during use and operation of the buildings, as well as at end-of-life deconstruction. This overall view is subdivided into five life-cycle stages, in turn comprising 17 life-cycle modules. The five life-cycle stages are: Product, Construction Process, Use, End of Life, and Beyond the System Boundaries (Figure 4). In Denmark, LCA of buildings apply a reference study period of 50 years. This reference study period is different from the expected lifetime of a building, serving as a time frame for the calculation.

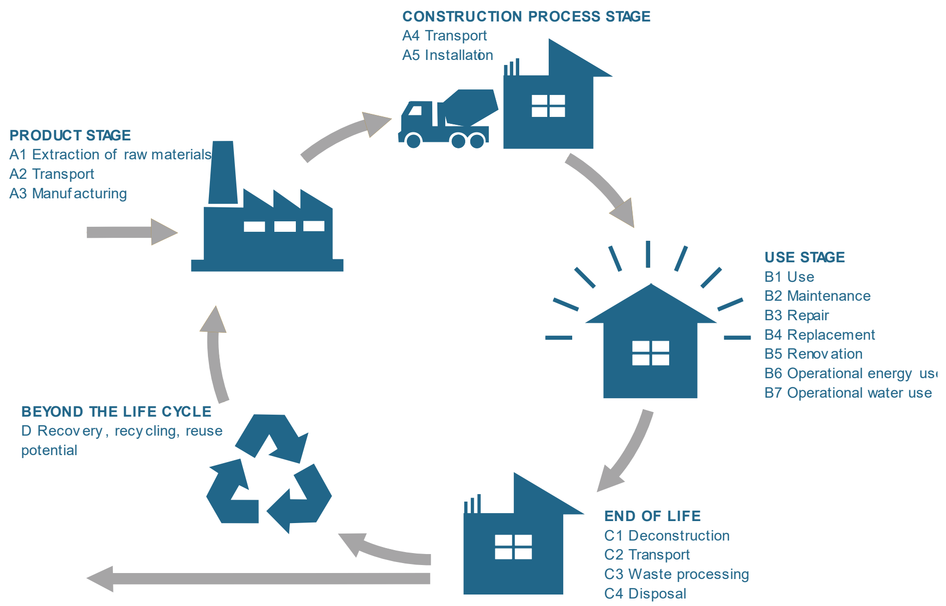


Figure 4 Life cycle of a building

Renovation occupies its own module (B5) in the building life cycle. This module is scenario-based, hence this module can be used to include expected future renovations in a building's lifetime when making an LCA of newbuild. However, when making an LCA of a building to be renovated today, the production of building materials used in the renovation will be allocated to the A-stage modules. The standard does not specify how to include existing materials in the building not affected by the renovation work.

Renovation projects will involve both the *new materials* added and *existing materials* – either deconstructed or preserved during the renovation process. To consider the existing materials, the life cycle of the building prior to the renovation is introduced. In this life cycle, the environmental impact from the Product and Use stages of the existing building has already occurred, see Figure 5.

Operating with two life cycles brings a methodical problem into the LCA calculation, namely the need to address both existing and new materials. For new materials, the calculation will be identical to the method for newbuild with all life-cycle stages from Product to End of Life (Figure 5). Existing materials will be part of both cycle 1 and cycle 2, and it is necessary, therefore, to determine a method to allocate environmental impact between the two cycles (Figure 5).

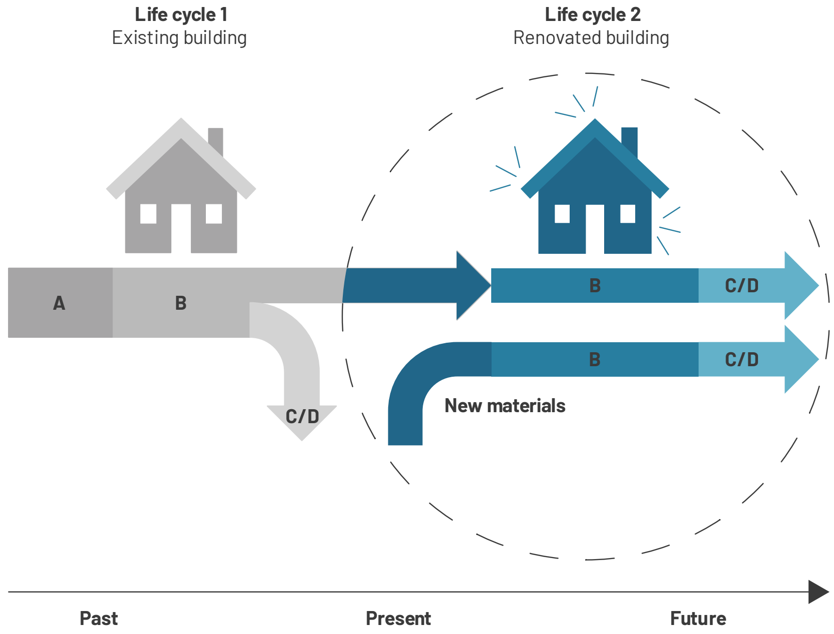


Figure 5 A renovation LCA overlaps two life cycles: the existing building and the renovated building. To assess environmental impact from renovation projects, it is necessary to determine a method to allocate environmental impact between these two cycles.

2.1 Examples of LCA methodology used in Denmark

There is limited experience in Denmark of making LCAs of renovations. Two different methods for calculating LCA of renovations are described in the test phase for the voluntary sustainability class FBK and the certification system DGNB.

Voluntary sustainability class (FBK)

In August 2022, 58 projects were registered for the FBK test phase, and 8 of these were renovation projects. The FBK class specifies the inclusion of the whole building in the calculation. This requires a mapping of materials from both the existing building and the new materials used for renovation. Some of the existing materials will be demolished during the renovation process. For such materials, impact is calculated from the End-of-Life stage. For existing materials preserved in the building, Replacement (B4) and End of Life are included (C3 and C4). For new materials, Production (A1–3), Transport and Construction (A4 and A5), Replacement (B4), and End of Life (C3 and C4) are included. Since replacement must be factored in for existing materials, the remaining useful life of the materials must be determined. Stages D (beyond system boundary) for new and existing materials are calculated separately. Operational energy use (B6) is included by determining the energy use for the renovated building via an energy-performance calculation. Calculations are carried out for a reference study period of 50 years. No reference value for renovations exists in the FBK voluntary sustainability class.

DGNB in Denmark

In August 2022, a total of 174 construction projects had been certified and of these, 7 were major renovations. DGNB certification of renovations applies to major renovations. The manual used for newbuild is also used for renovation, where the focus is on the new materials added to the building. DGNB only includes new work done to the building, i.e. the new materials introduced during the renovation process. For these materials, Production (A1–3), Replacement (B4), and End of Life (C3 and C4) are included. Since no methodology has yet been defined concerning the type of material impact to include in a renovation LCA, deconstruction of existing materials during the renovation is only included in some cases. Operational energy use (B6) is also part of the LCA for the renovated building and is determined by an energy-performance calculation. The reference study period is set at 50 years as for newbuild.

DGNB now also includes the construction process (A4 and A5) both for newbuild and major renovation work. However, not to the extent of complying with the reference value, since this does not include A4 and A5. Stage D, ”Beyond the System Boundary”, is also included separately. DGNB uses the same reference value for renovation as it does for newbuild. Although material consumption is lower for renovation projects, energy consumption will typically be higher.

2.2 Examples of LCA methodology used in Europe

Like Denmark, other European countries also apply LCA for renovation work to a limited extent. So far, no countries have yet included limit values for LCA of renovations in their national legislative framework.

Radical large-scale renovation work is included alongside newbuild in many standards for LCA of buildings and in sustainable building certificates which use LCA.
This is true of the new European framework for sustainable construction Level(s), for example. Major renovation work is also included in the German BNB (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen (Ministry for Housing, Urban Development, and Construction, 2022)), which is a certification scheme for public buildings, and in the standard for building LCA in Switzerland, defined by the professional association of engineers and architects (SIA). In Switzerland, specific limit values for renovations are also defined. The limit values are subdivided into embodied impact, operational impact, and transport impact affecting users of a building. The limit values are defined for the categories climate impact, primary energy, and non-renewable primary energy. There are no statutory requirements to comply with these limit values.

The definition of large-scale renovation work is rarely clear. In an energy demand context, a major renovation can be defined as the share of the building envelope being renovated or the cost of the project (European Commission, 2021), which is also used as the definition in Level(s). However, in the European standards for sustainable construction work *refurbishment* is in focus with the draft proposal for a European standard for sustainable refurbishment of buildings (CEN/TC 350, 2022). This defines refurbishment as a major intervention, including changes in the ”space plan” and thus not merely energy-related interventions.

In the LCA methods used, impact from existing materials is typically included only to a limited extent, for example, from replacement of existing materials in the Use stage. However, some schemes do exist, including the French certification scheme HQE, where existing materials are included to a larger extent, for example, with ”residual impact” from the production of materials which have not yet reached the end of their estimated lifetime at the time of renovation.

3 Specification of method

3.1 Case studies and LCA specification of method

Since LCA is rarely used for renovation purposes, very few data were readily available for use in this analysis. The first part of the project, therefore, was a search for cases from Danish sector stakeholders. As a result of this and prior to the calculations, data were collected from 29 renovation cases made available for this project and used in support of assessment methods to define limit values. Based on data collection and calculations from real-life renovation cases, it is possible to know which type of renovation work was carried out in the 29 cases, how much data is available, its quality, and its environmental load. The cases are a mixture of DGNB-certified buildings, housing schemes, and a few other projects which BUILD gained access to via sector stakeholders. The 29 cases comprise 20 housing projects, 4 office buildings, 2 hotels, 1 hospital, 1 institution, and 1 building for cultural use, see Figure 6.

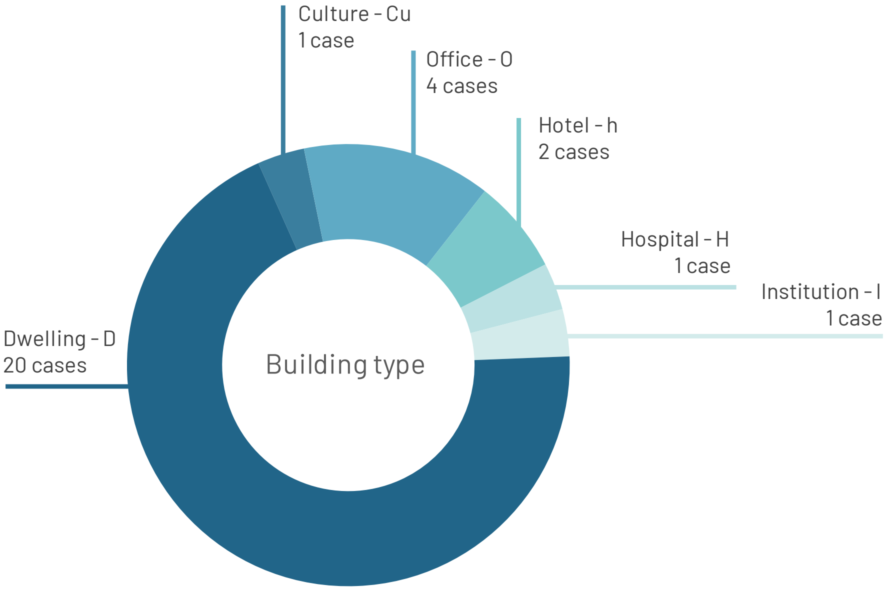


Figure 6 Breakdown of renovation cases according to building use

Besides differences in usage type, the buildings also vary according to year of construction (from 1905 to 2001). Figure 7 indicates that most buildings were constructed during the period 1960–1980. Figure 8 shows the breakdown according to area size, indicating that the area in 26 of the 29 cases exceeds 1,000 m^2, 11 of these being between 1,000–5,000 m^2, and that 10 are <10,000 m^2, in other words major renovation projects. Of the three cases under 1,000 m^2, only one is a single-family dwelling.

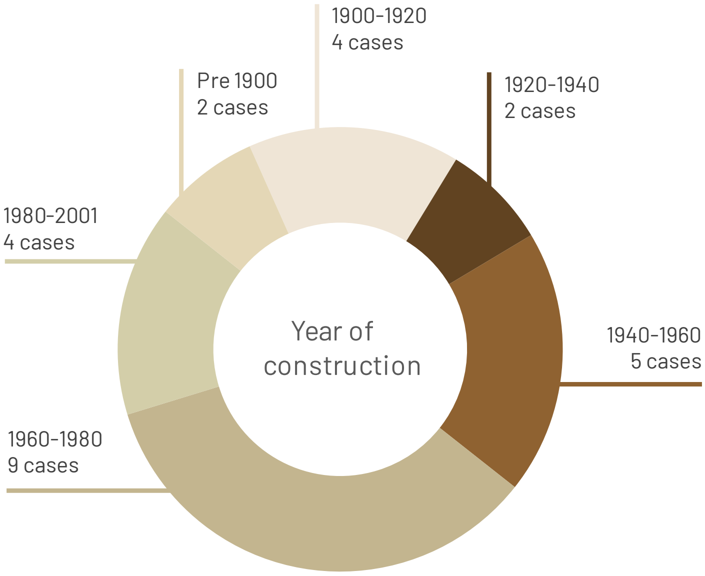


Figure 7 Breakdown of renovation cases according to year of construction and area (over 1,000 m²)

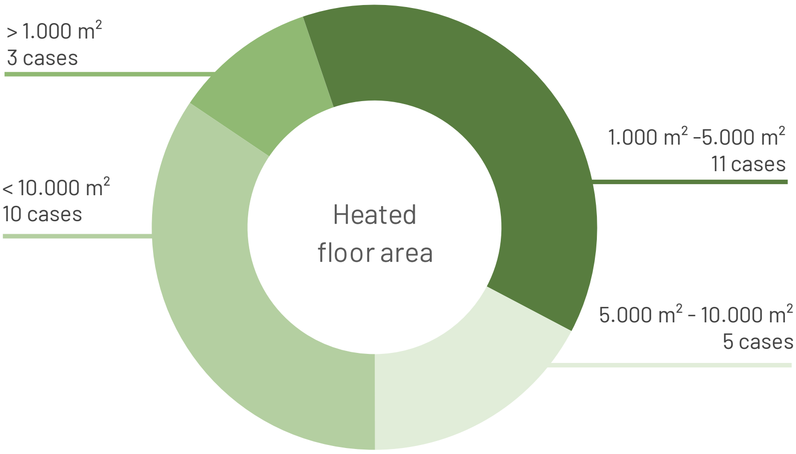


Figure 8 Distribution of renovation cases according to heated area

Extent of renovation

Figure 9 shows the extent of the renovation work and specific renovation procedure undertaken for each of the 29 cases. Based on nine categories, this indicates which building components have undergone renovation and which have been added to the building.

Further, the right-hand side of Figure 9 indicates whether the renovation means a change in the plan arrangement and whether it affects the floor space either in the form of an addition, increasing the floor space↑, or by eliminating floor space↓. In 8/9 of the cases, floor space is increased.

Figure 9 shows replacement and window additions to be the commonest renovation procedure. Generally, re-insulation of building components tends to accompany roof and exterior wall renovations, affecting energy consumption. In most cases, a renovation will also result in new water and heating installations.

Please note that Dwelling B2 only consists of added elements, since the renovation project chiefly consists of an addition.

23 of the 29 renovation projects comprise, as a minimum, an addition or replacement of three building components in the building envelope. Further, in all 29 case studies, renovation work meant changes in the plan arrangement, resulting in replacement of interior walls, flooring, and ceilings. The collected cases can thus be considered major renovation projects and will thus not reflect scenarios involving minor renovation work in a building.

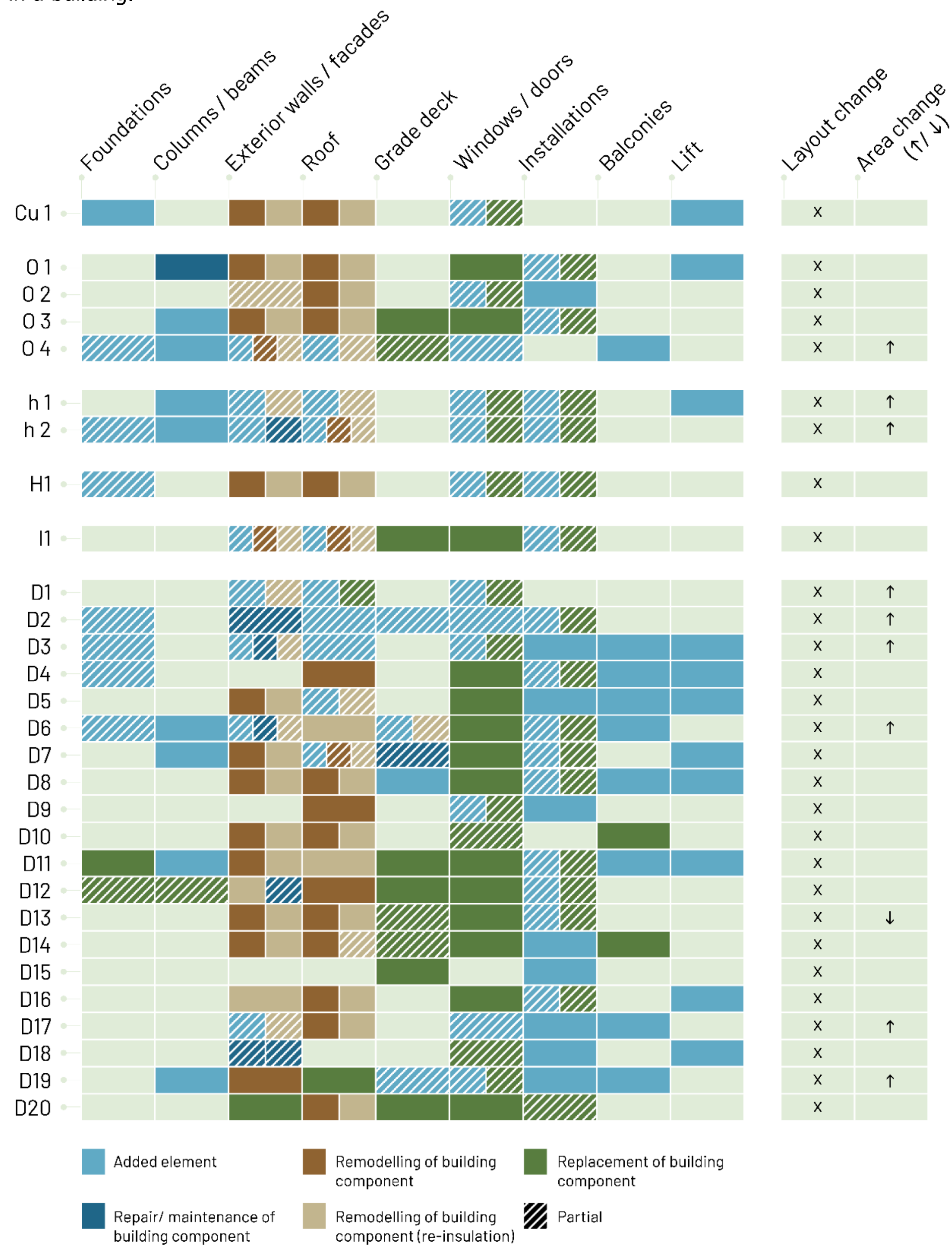


Figure 9 shows the extent of the renovation and specific renovation procedure undertaken for each of the 29 cases

The limited data set for LCA of renovation work is problematic in terms of defining a well-founded method and benchmark for limit values concerning environmental impact of renovations. Since there has been virtually no tradition of making LCAs of building renovation in Denmark, relatively much project time was spent on obtaining access to data on renovation projects.

Despite having contacted the sector, it only proved possible to analyse 29 building cases within the project framework.

LCA methodology

LCA calculations follow the calculation method specified in the standard EN 15978 for assessing the environmental quality of buildings. The calculation applies the same life-cycle stages and modules (see figure 10) used in the future requirements for calculating climate impact of newbuild. This also applies to defining the building components used in the calculation when conducting LCA of renovating entire buildings. This means that materials are not included for kitchens and bathrooms, for example, although they play a significant role in the renovation of existing buildings. Calculations are made in LCAbyg 5 (BUILD, 2022). Environmental load from existing materials is not included. The significance of existing materials is examined in more detail in section 6.2.

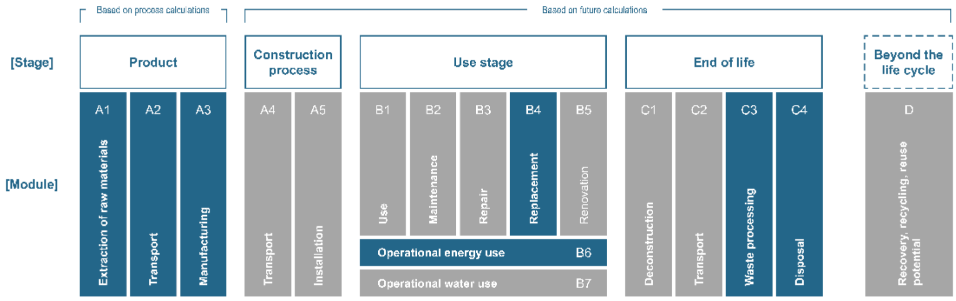


Figure 10 Selected life-cycle stages and modules cf. LCA requirements for newbuild in BR18

3.2 Renovation types defined

It would be a good idea to base future LCA requirements on the existing Building Regulation requirements for renovation. For this analysis, we use the energy requirements for renovations as our starting point and the renovation types defined there.

Since 2006, the Building Regulations have specified requirements for certain types of renovation work to achieve energy efficiency by re-insulating if it is viable and does not involve a risk of moisture damage. For future requirements for LCA of renovation work, it makes sense to apply and retain Building Regulation definitions to the greatest extent possible.

To appreciate the renovation requirements in the Building Regulations (BR18, 2022), it is necessary to understand the various renovation types/situations. The Building Regulations differentiate between the following situations:

Change of use

Change of Use is designated as one or more rooms or a building being converted to serve a new purpose with significantly higher operational energy use – for example when an outbuilding or a loft is converted and used for accommodation, or when a warehouse or stable is converted into offices. Energy requirements for Change of Use (section 267) can be complied with by using an energy-performance calculation or complying with the U-value requirements in section 268. Structural conditions could mean that linear thermal transmittance requirements cannot be complied with, for example. If so, this can be compensated for by other energy solutions (section 269), such as re-insulation, solar heating systems, heat pump systems, or photovoltaic modules. This can be documented by a thermal-loss calculation (sections 271–272) or an energy-performance calculation.

Additions

Adding square metres to an existing building constitutes an addition. This could be a new wing or top storey with loft rooms providing added floor space. Energy requirements for additions should be met by using an energy-performance framework, a heat-loss framework, or by insulating individual structures to comply with the U-values in section 268. If the energy-performance framework for additions is used, the framework will only apply to the addition. The scope of the energy-performance framework for the additions is calculated based on the building's total floor space. Alternatively, the requirements can be met by complying with the U-values in section 268 or the heat-loss framework in section 272.

Replacing building components (the whole roof or floor construction, for example).

We talk of replacing a building component when it is deconstructed/demolished without preserving a single part, including the supporting structures, and an entirely new building component is constructed in its place. When replacing building components, the component must always be insulated, as a minimum, in accordance with requirements in section 279, regardless of viability. Note that roof covering or timber facing, for example, is categorised as conversion a building component.

Conversion (for example, a new roof covering or facade cladding).

The definition of 'conversion' is key to fully understanding the renovation requirement. Conversion involves renovation of a building component (roof/loft construction, exterior wall, floor construction), often because an obsolete layer of material either inside or outside needs replacing. In conversion work, supporting structures in the building component will usually not be replaced by new ones. If renovation work is categorised as conversion, Building Regulation requirements specify re-insulation if it is viable and does not involve a risk of moisture damage.

Structural alterations

The Building Regulations also specify energy requirements for structural alterations of building components (section 270), such as constructing a new dormer or a new window in the facade. The alterations must comply with requirements for U-value/linear thermal transmittance cf. section 268. Should it prove impossible to comply with the requirements, this can be compensated for by using other energy-efficient solutions. This can be documented by a thermal-loss calculation (sections 271–272) or an energy-performance calculation.

Repairs (for example, replacing a few roof tiles, paintwork, repair of rendering)
Repairs cover minor changes which are not subject to requirements for viable energy efficiency. This would typically involve minor work such as repairing the facade rendering, replacing a single rafter or a few timber boards in a facade, or paintwork. Storm-related damage, pipe burst, or minor fungus decay not affecting the main part of the building component, for example, are classed as minor repairs and not subject to viable re-insulation.

Other renovation work

"Other Renovation Work" is not a Building Regulation category but added in this report to cover renovation work at building level which can neither be classed as Additions or Change of Use. This means that it may cover a broad range of renovation types from simple interventions to deep renovation work and transformation.

According to the standard EN 15978, deep renovation could be defined as modernisation and refurbishment to an extent that will bring the existing building up to acceptable levels (Danish Standards, 2012). Specifically, in this report, deep renovation is considered renovation comprising more than one building component in the building envelope, such as roofs and windows.

3.3 How to comply with energy requirements

Renovation classes

Since 2015, Building Regulations have comprised a voluntary opportunity for building owners to carry out more holistic renovation of buildings, where requirements, instead of applying to building-component level, apply to building level in the form of an energy-performance framework. The purpose of voluntary renovation classes is, for example, to provide alternative means of meeting Building Regulation requirements for components as specified in chapter 11, sections 274–279 for conversion. When using the energy-performance framework for existing buildings, the requirements for individual building components no longer apply, giving a free rein to select better insulated windows and increase loft insulation to reduce the thickness of facade insulation. This gives ambitious building owners and building designers more autonomy. However, requirements in chapter 11 sections 257 and 258 must always be complied with when replacing a building component or installation in its entirety.

Exceptions

Listed buildings or buildings of special architectural interest such as churches, etc. are to a certain extent exempt from the renovation requirements. Likewise, renovation that involves a risk of moisture damage may be exempt from requirements, such as renovation of basements, floors, and interior renovation work of exterior walls.

Energy-performance calculation (calculating energy needs)

Requirements for the classes newbuild, additions, change of use, and renovation can be based on an energy-performance calculation. The calculation must document that the building's calculated energy need is less than that laid down by the energy-performance framework in the Building Regulations. It is a standardised calculation of the need for operational energy for heating, ventilation, hot water, cooling, and possibly lighting multiplied by the relevant energy factor for each driver.

Thermal-loss calculation

A thermal-loss calculation is a two-part calculation. In the first part, it is determined how much heating an addition or a building with changed use would need if built to specifically comply with the U-value requirements in section 268 with a window area of 22%. Following this, a calculation is made using the actual U-values, linear thermal transmission, and window/door areas. If the linear thermal transmission calculation is less than the framework defined by the first calculation, the requirement is met.

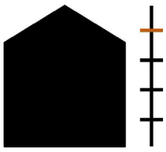
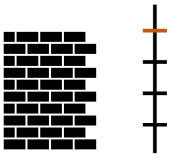
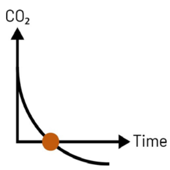
Calculating energy performance for specific renovation interventions

Calculating the energy performance for a specific intervention, for example, re-insulating an exterior wall, could be based on the so-called degree-day method, using the difference in U-values before and after the renovation to approximate expected energy optimisation. The method is only applicable in buildings that need heating during the period mid-September to mid-May at a room temperature of 20 degrees C. If the indoor temperature deviates from this, the number of degree days/hours can be adjusted. Denmark has 3,765 degree days/year, corresponding to 90,360 degree hours, and the energy efficiency can be calculated using the formula: $(U_{before} - U_{after}) \times 90.36$ [kWh/year per m^2].

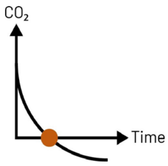
3.4 Definition of limit values

We have drawn up six possible solutions for a potential limit value for renovation work. The six proposed solutions have been defined to embrace solutions at building level, where the building is viewed as an entity, and at building-component level where building components can be treated separately. Further, the proposed solutions should reflect a variation in the calculation complexity required when the limit value must be complied with.

Table 2 Definitions of limit values

Limit value 1 – Benchmark for the total building  In keeping with the requirement for newbuild, this limit value views the building as an entity from the perspective of a limit value of the aggregate environmental impact from the renovation work, including impact from materials and operational energy. It can be related to the renovation classes, where a building owner would view the renovation work at building level. **Data requirements:** To define limit values for the entire building, it is necessary to make a full-scale LCA of the whole renovation project, mapping all materials. A mapping of materials should list all activities in the building over a study reference period of 50 years. Further, it is necessary to make an energy-efficiency calculation for the building to incorporate heating and power requirements in the calculation.
Limit value 2 – Benchmark for renovating building components  In this scenario, the renovated building components are evaluated separately with a separate quality standard being introduced for the individual building components. This quality standard will apply to the impact from materials and operational energy. **Data requirements:** The building component must be mapped based on the materials added during the renovation (plus existing ones, if applicable). To consider energy consumption a simple thermal-loss calculation can be made through the relevant building component, where the only factor required is the U-value after renovation. The calculation will be limited to apply to 1 m² of building component.
Limit value 3 – EPBT of the building's (energy)retrofit  A limit value assessing the environmental payback time of an energy retrofit, i.e. a benchmark for the time it takes for the environmental impact from materials and the reduced impact from the energy optimisation to balance out after the renovation work. This quality standard makes use of two scenarios: how does the building look (1) before the renovation and (2) after the renovation. The energy efficiency must reflect the total building based on the two scenarios. **Data requirements:** An LCA calculation must represent the whole building, including all renovation interventions. For this type of quality standard comparing an existing building with a renovation scenario, it could be argued that deconstruction of all existing materials will occur in both scenarios and could thus be left out of the calculation. The mapping will therefore only concern the new materials added during the renovation. When documenting the potential energy saving resulting from the energy retrofit, two energy-performance calculations are required, one covering the existing building before renovation and one the renovated scenario.

Limit value 4 – EPBT of (energy)retrofit of the building component



This limit value is based on the same principle as quality standard 3, which only involves the climate payback time for individual energy-retrofitted building components. Again, the building component is subject to two scenarios: how does the building look (1) before the renovation and (2) after the renovation. Similarly, the energy saving represented by the two scenarios only relates to individual building components.

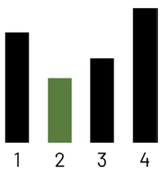
Data requirements: Materials are limited to the single building component. Since a comparison of the building component is made before and after renovation, the mapping of materials can be limited to the new materials added during the renovation process. Deconstructing materials in the existing building component will occur in both scenarios. The energy saving for individual building components can be determined from their U-value before and after renovation by using the degree-day method (Mortensen, Kanafani, Rose, & Hjorth Richter, 2018). The limited calculation will only apply to 1 m² of building component.

Limit value 5 – LCA reference as a benchmark for renovation

This limit value addresses renovation work at building-component level for conversion and replacement of building components. Material consumption and thermal loss are included. The benchmark is modelled on an LCA reference based on materials in the existing building component before renovation. The LCA reference corresponds to renovation work using identical materials and a U-value, including insulation thickness, cf. BR18 component requirement, section 279. The limit value will therefore always depend on the specific building component in the specific project, intended to ensure that solutions resulting in higher carbon emissions than those of the benchmark are avoided.

Data requirements: Only environmental impact from materials is used in this calculation. For the reference calculation, all relevant existing materials must be mapped for each individual building component. To document that the renovation work does not exceed the reference, all relevant new materials must be mapped. The limited calculation will only apply to 1 m² of building component.

Limit value 6 – Requirements for comparing solutions

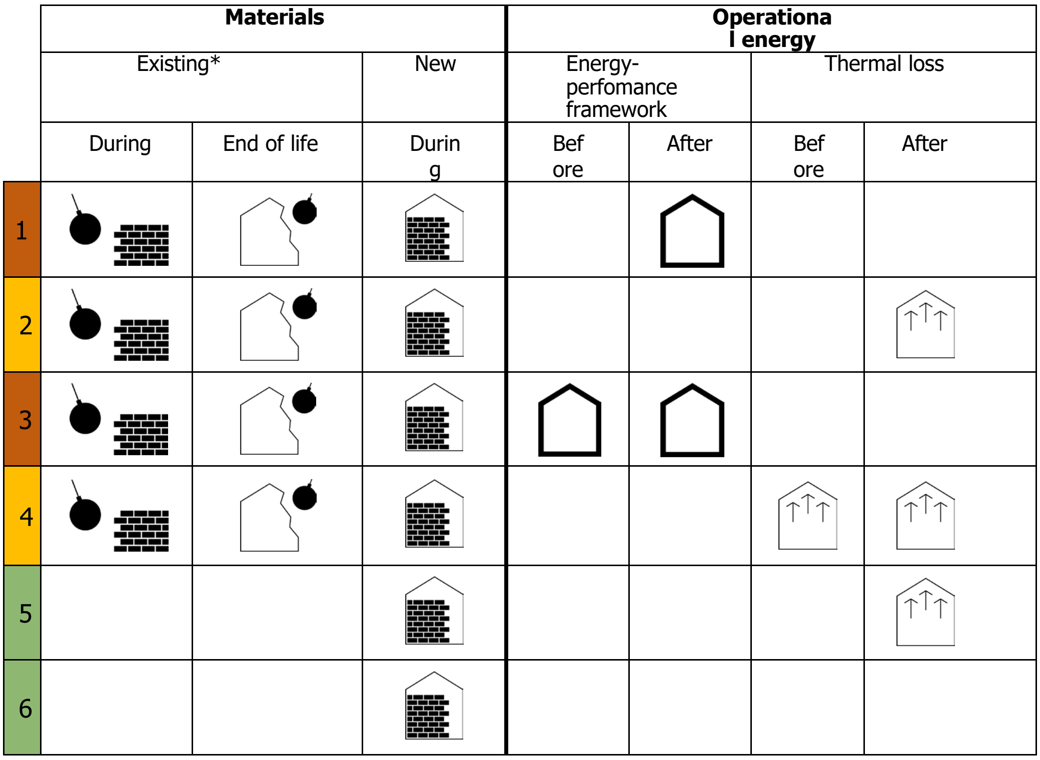


This limit value is different from the above five, as there is no specific value that must be complied with, but there are, on the other hand, requirements for conducting a variant analysis of material choice. This could apply to specific materials or to the entire construction of a building component. The calculation can be limited to apply to 1 m^2 of building component.

Data requirements: The application of the variant analysis is limited to the material impact from the selected variants. For this quality standard, it is unnecessary to map material quantities used for the renovation work, since the comparison is made per 1 m^2 of building component. It will only be necessary to collect data from the new materials in each variant used.

Figure 11 below shows accumulated data requirements for the six limit values for materials and operational energy use. For each limit value, the complexity of collecting and treating data is indicated by three colours.

LCA of materials is limited. A simple calculation of thermal heat loss can be made.	An LCA not requiring material quantities but must include all material layers in a building component. One or more thermal-heat-loss calculations must be made.	Extensive material mapping and LCA calculation. One or more energy-performance calculations are required.



*depends on LCA methodology

Figure 11 Overview of data requirements for the 6 limit values

3.5 Combination of renovation types and limit values

It is not possible to combine all renovation types with all types of limit values. The reason for this is the use of the levels 'building' and 'building components' within both renovation types and limit values.

Figure 12 indicates the combinations investigated in this report. In the following section, these combinations will be assessed by listing their advantages and disadvantages. The analysis also includes an assessment of the methods based on LCA results of the 29 renovation case studies.

Limit values		1. Overall renovation requirements in keeping with requirements for newbuild	2. Requirements for renovation of building component	3. EPBT of building renovation	4. EPBT of building-component renovation	5. Reference calculation for benchmark of renovation	6. Comparison of solutions
Building level	Change of use	X	At building-component level, the category is covered by B, O, and U	x	At building-component level, the category is covered by B, O, and U	At building component level, the category is covered by B, O, and U	At building component level, the category is covered by B, O, and U
Building level	Additions	X	At building-component level, the category is covered by U	The lack of a 'before' scenario makes it impossible to determine payback time	The lack of a 'before' scenario makes it impossible to determine payback time	The lack of a 'before' scenario makes it impossible to do the reference calculation	At building-component level, the category is covered by U
Building level	Other renovation work*	X	At building component level, the category is covered by B, O, and U	x	At building-component level, the category is covered by B, O, and U	At building-component level, the category is covered by B, O, and U	At building-component level, the category is covered by B, O, and U
Building-component	Structural alterations: B	Not detectable at building-component level	Covered by category U	Not detectable at building-component level	Covered by category U	x	x
Building-component	Conversion: O	Not detectable at building-component level	x	Not detectable at building-component level	x	x	X
Building-component	Replacement: U	Not detectable at building-component level	x	Not detectable at building-component level	x	x	x

* Projects not included in Change of Use or Additions. May cover both minor/simple renovation work and large-scale extensive renovation such as transformation.

Figure 12 Combinations of renovation type and limit values investigated

4 Limit values for renovation: possibilities

This section evaluates the scope for specifying limit values based on the six renovation categories cf. section 3.2. Evaluation of limit values starts by assessing advantages and disadvantages. The limit values marked by crosses in **Figure 12** are evaluated within individual renovation categories.

4.1 Change of use

For *Change of Use*, advantages and disadvantages are described for **limit value 1: benchmark for the total building** and **limit value 3: EPBT of the building renovation** cf. Table 2.

Change of Use covers cases which may show great variations in environmental impact from materials. Impact corresponding to **limit value 1** (restricted to materials) is shown in Figure 13. Material climate impact from Change of Use is lower than impact from newbuild with a median value of 3.70 kg CO_2eq/m^2/year. However, the number of cases is insufficient to assess whether they differ significantly from the rest of the renovation case studies. Introducing specific limit values to this renovation type will require a more extensive data set.

In keeping with energy requirements, it is possible to use **limit value 1** in combination with limit values for building components. Thus, it is possible to meet either individual *component requirements* or a *component-requirement framework*. A limit value for the whole building gives more scope for combination of potential solutions, whereas implementing requirements for building components calls for less work.

To meet this limit value may require a mapping of materials from all renovation interventions in the building. Further, an energy-efficiency calculation is needed – not required at present for renovation work and therefore not necessarily automatically included in all projects. It is a good idea to consider whether an energy-efficiency calculation of a renovation project should be made, which could mitigate the problem of missing data and standardise methods for projecting renovation work.

Advantages and disadvantages of limit value 1 for the renovation type *Additions* are summarised in Table 3.

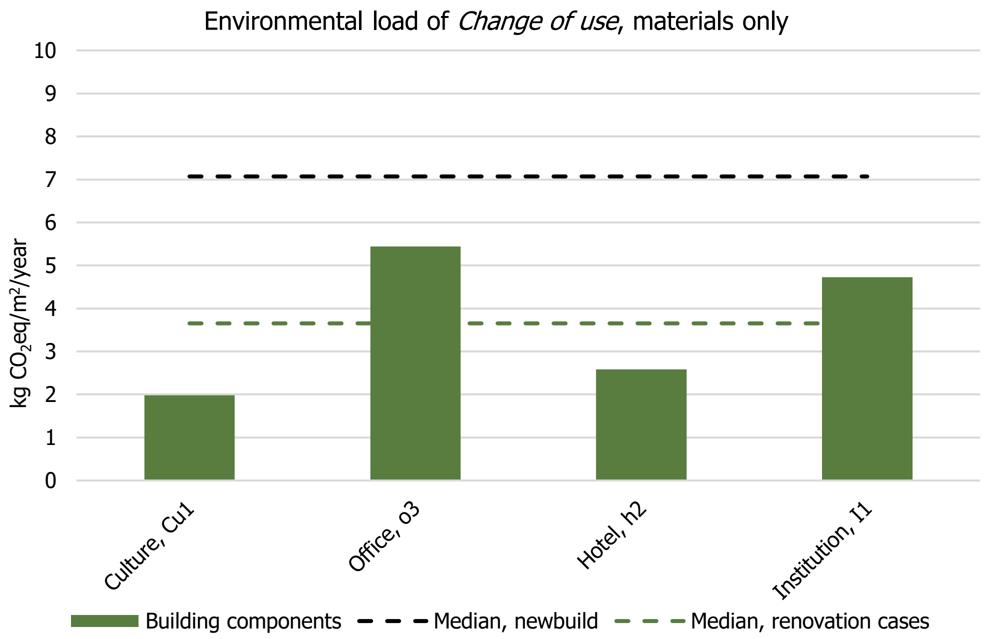
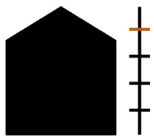


Figure 13 Environmental impact from renovation projects in the Change of Use category. Only results from material impact are shown, since data for operational energy use were only available for I1.

Table 3 Advantages and disadvantages of limit value 1 for the category Change of Use

Limit value 1	Advantages	Disadvantages
	Free choice of solution: desirable solutions may offset the less desirable ones. Possibility of specifying requirements based on renovation case studies in Change of Use or as a percentage of newbuild.	The extent of renovation types may vary considerably, and the effect of limit values therefore be less clear. An energy-efficiency calculation is required, which is not necessarily made for renovation work (consider obtaining data from the energy-rating labelling scheme).

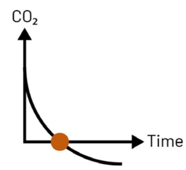
Limit value 3 may prompt considerations about including energy-saving interventions in the renovation work which could reduce the building's total energy consumption. This will achieve CO_2 optimisation of operational energy use that might offset the environmental load from the materials used for renovation. This could be a method to promote optimal renovation solutions which will not increase environmental load relative to the building's benchmark.
The application of this limit value is restricted to renovations resulting in saving energy. An energy-efficiency calculation of the building is required for this calculation before and after renovation work to document the energy saving. To meet this limit value, therefore, could increase the workload considerably.

Energy savings being a decisive factor in a limit value for renovation work might impede comparisons between buildings with different energy benchmarks (pre-renovation energy consumption). A building with poorly insulated building components and high energy consumption will achieve greater energy savings when energy requirements are met than buildings with a lower pre-renovation energy consumption.

Since, per definition, Change of Use means lower pre-renovation energy needs, energy savings for this renovation category are unlikely in most cases, and it is not possible to calculate the greenhouse-gas payback time. It can be used in cases where a renovation leads to energy savings.

Advantages and disadvantages of limit value 3 for the renovation type *Change of use* are summarised in Table 4.

Table 4 Advantages and disadvantages of limit value 3 for the category Change of Use

Limit value 3	Advantages	Disadvantages
	The effect of the energy retrofit is evident.	Only possible for renovations which reduce energy consumption. Requires energy-efficiency framework before and after renovation (consider obtaining data from the energy-rating labelling scheme). Possible solutions are governed by the building's energy benchmark.

4.2 Additions

For *Additions,* advantages and disadvantages are described for **limit value 1: benchmark for the total building** cf. Table 2

Limit value 1 determines the overall impact from materials and operational energy use for the whole building, corresponding to newbuild. Ranking environmental impact at building level enables a free choice of solutions: ”desirable” solutions may offset ”less desirable ones” from an environmental impact perspective.

The availability of data for operational energy use can be problematic. This is because making energy-performance calculations for additions is not yet a requirement. Consequently, a limit value would require that either an energy-performance calculation was made for the project, or an option to only comply with a limit value exclusively for the material consumption. If an energy-performance calculation is made for the whole project, it can be difficult to subdivide energy requirements between the addition and the existing building.

Material consumption for additions can be regarded as identical to that of newbuild, since all building components are new. This is also evident in the findings from four new additions from the renovation case studies in Figure 14. The graph shows material emissions from the four additions with a calculated median value of approx. 6 kg $CO_2eq/m^2/year$. A comparison with newbuild shows the median value of approx. 7 kg $CO_2eq/m^2/year$ (black dotted line), representing material consumption of 60 newly-built housing (the report *Whole Life Carbon Assessment of 60 Buildings*). This enables limit values to be specified in line with those for newbuild. Further, it is possible to combine them with limit values for building components.

Advantages and disadvantages of limit value 1 for the renovation type *Additions* are summarised in Table 5.

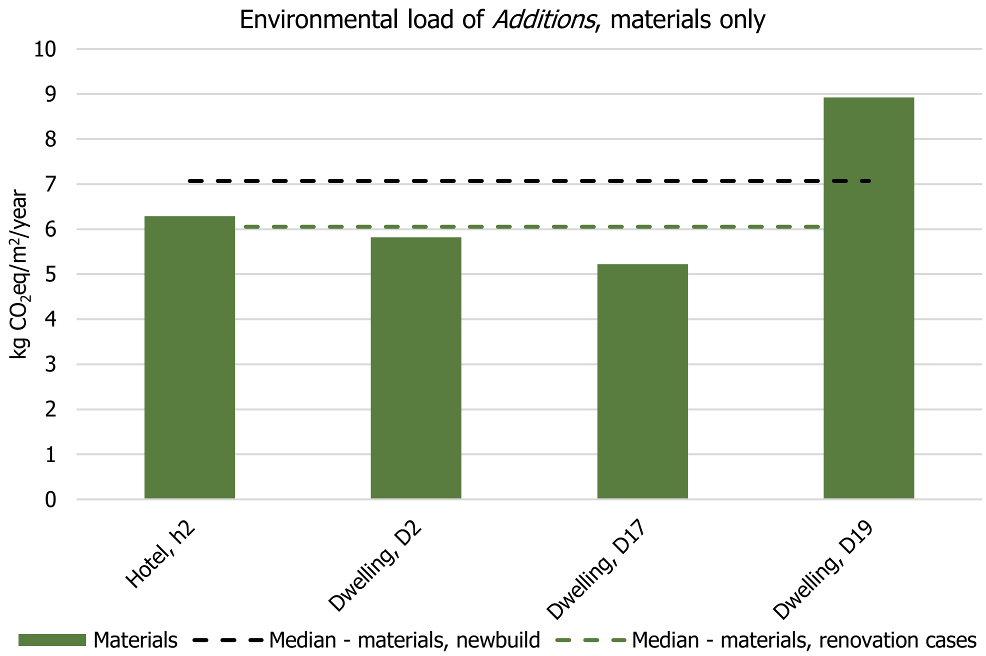
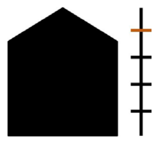


Figure 14 Environmental impact from additions. Only results for material impact are shown, since no separate data for operational energy exist.

Table 5 Advantages and disadvantages of limit value 1 for the category Additions

Limit value 1	Advant ages	Disadva ntages
	Free choice of solutions: desirable solutions may offset less desirable ones. Option to specify requirements corresponding to LCA for newbuild. Could be combined with requirements for building components.	An energy-efficiency calculation is required, which is rarely completed for addition projects (if an energy-rating label exists, data could possibly be obtained from there).

4.3 Other renovation work

For *Other Renovation Work,* advantages and disadvantages are described for **limit value 1: benchmark for the total building** and **limit value 3: EPBT of the building renovation** cf. Table 2.

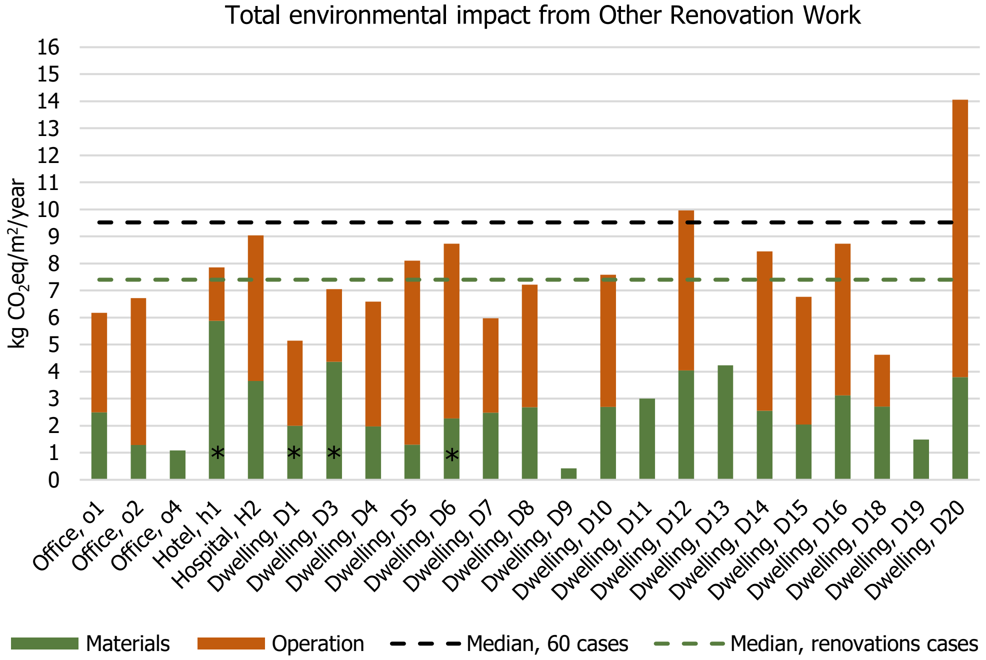
As outlined in section 3.2, *Other Renovation Work* covers all renovation work that is not classed as Additions and Change of Use. This means that renovation work span both one-off interventions and radical renovation projects. Impact corresponding to **Limit value 1** are shown in Figure 15. Median value for the total emissions is 7.4 kg $CO_2eq/m^2/year$. In future, it would be a good idea to categorise this renovation type (Other Renovation Work) in more detail to facilitate comparison of projects.

Limit value 1 determines the overall impact from materials and operational energy use for the whole building. Ranking environmental impact at building level enables a free choice of solutions: ”desirable” solutions may offset the ”less desirable ones” from an environmental impact perspective. When both operational energy use and materials are included, it becomes possible to consider renovation work where a special effort has been made to reduce energy consumption.

Precisely because the limit value is an incentive to reduce the building's total operational energy needs, it may be difficult for buildings with high energy use to comply with it. In such situations, it will be necessary to carry out very radical renovation work, which might increase the need for materials.

Besides, renovation work may provide new functions in the building compared to earlier, including lifts, balconies, etc. tending towards substantial material cost rather than saving energy.

The limit value method emulates the one for newbuild in the Building Regulations. Also for extensive renovation work, the projects could be compared to newbuild to discover whether the performance over the reference study period is better or worse than for newbuild.
It can prove difficult, for minor renovation work to comply with an overall limit value covering both materials and operational energy use, so this limit value will be best suited to major renovation work and thus not always appropriate for the renovation category "Other Renovation Work"



* Renovation case study including an addition where it is not possible, in the LCA model, to separate the addition from the rest of the project.

Figure 15 Environmental impact from renovation projects relative to the renovation type "Other Renovation Work". The median value is a total for materials and operational energy use and only for those 18 case studies where the operational energy use is known.

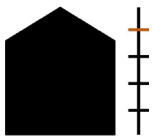
Data accessibility for this limit value can be a problem. An energy-efficiency calculation is needed which, at present, is not a requirement for renovation work. However, if an energy-efficiency calculation was made to enable compliance with the renovation classes, data would be obtainable. If an energy-rating label is available, data on energy needs could possibly be obtained from this.

To meet this limit value may require a mapping of materials from all renovation interventions in the building.

Combining this limit value with limit values at building-component level is a practical option emulating the energy requirements for renovation, where building owners can decide whether calculations should apply at building or component level.

Advantages and disadvantages of limit value 1 for the renovation type *Other Renovation Work* are summarised in Table 6.

Table 6 Advantages and disadvantages of limit value 1: benchmark for total building in the category Other Renovation Work

Limit value 1	Advantages	Disadvantages
	Free choice of solutions because environmental impact is calculated at building level: desirable solutions may offset less desirable ones. Can be combined with requirements at building-component level. Possibility of comparing the project with newbuild.	Difficult to specify a quality standard for buildings with varying energy consumption before renovation work. Does not allow for added functions, such as lifts, in the building. Could be difficult for certain interventions to comply with the limit value. An energy-efficiency calculation is required, which cannot always be determined for renovation work (consider obtaining data from the energy-rating labelling scheme).

Limit value 3 determines the EPBT for the whole building, i.e. the number of years before environmental impact from materials has been offset relative to the impact saved from the building's energy consumption.

The effect of energy retrofittting is emphasised in this limit value, which will boost focus on efficient energy retrofitting in terms of minimising material consumption in projects. The function of the limit value is to address the changes made relative to the existing building. Consequently, the limit value does not show the building's overall performance but only the changes and effects of the renovation interventions.

The existing conditions in the building are significant in terms of energy savings to be achieved: the more insulation before renovation work, the smaller the effect of re-insulation.

It is important to note that a short EPBT is not consistent with high CO_2 savings after 50 years. This can be documented from eight renovation case studies under *Other Renovation Work*, where energy consumption before and after renovation is known, see Figure 16. Figure (a) shows that the full-scale renovation of Dwelling, D15 results in a EPBT of approx. 2 years, whereas the EPBT from the renovation of Office, o1 will be offset after about 15 years. Office, o1, therefore, represents the worst renovation work of the two in terms of environmental impact. The picture changes in figure (b), where, after 50 years, Office, o1 now achieves a higher impact reduction of 210 kg CO_2/m^2/year because of the renovation than Dwelling, D15 with its 78 kg CO_2/m^2/year. The reason is the differences in the extent of renovation interventions. A minor intervention securing energy savings can be offset quickly in terms of environmental impact. Nevertheless, the energy saving will be very small seen in a 50-year perspective, as only a small part of the building has been upgraded. Figures (16 a) and (b) also illustrate cases where a short EPBT can result in high CO_2 savings after 50 years. This can make it difficult to determine a limit value. It is essential to decide whether impact-reducing interventions are required immediately or sometime in the future. A possibility would be to assess EPBT based on the extent of renovation interventions.

Further, it is important to stress that the expected development of emission factors will mean that the EPBT of an energy retrofit will increase over time, since emissions from energy use in the buildings will drop.

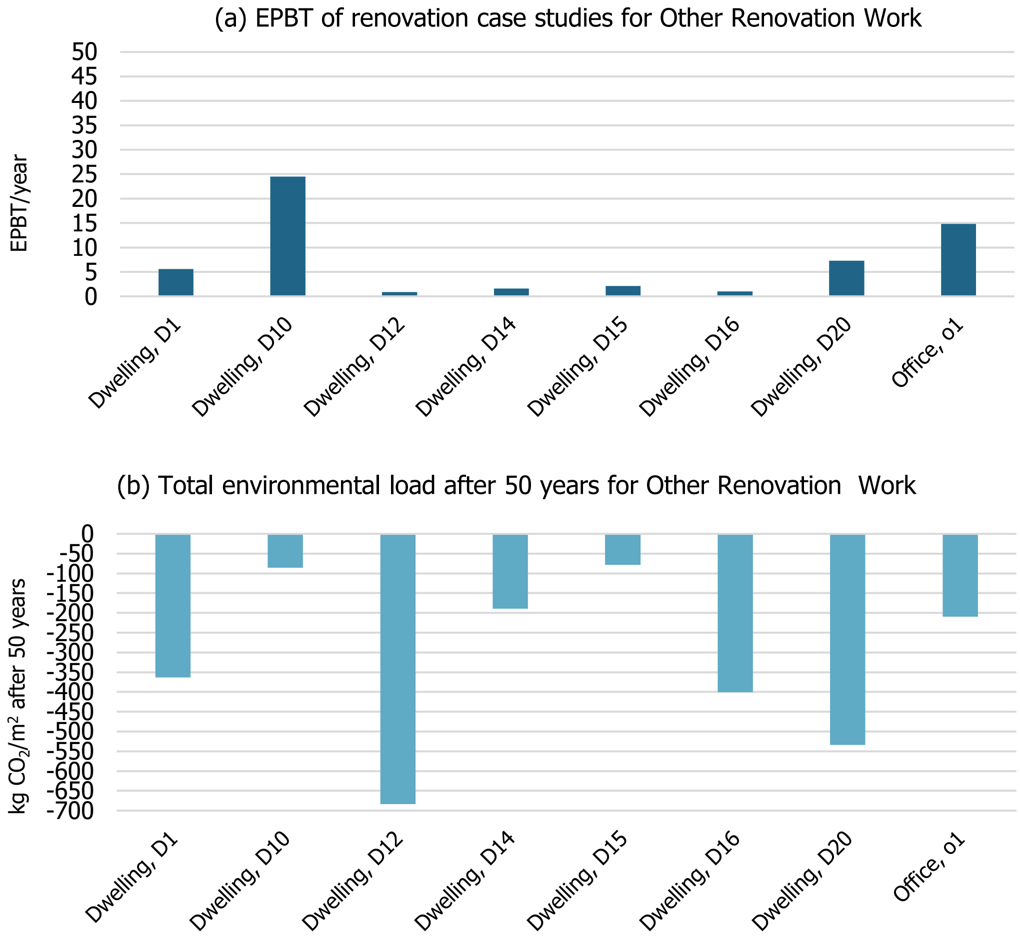


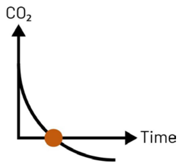
Figure 16 top, figure (a) shows the environmental payback time (EPBT) for whole life carbon and, bottom, figure (b) shows the total environmental load over 50 years for the category *Other Renovation Work*

Data can be an even greater problem here because an energy-efficiency calculation is required both before and after the renovation.

Advantages and disadvantages of limit value 3 for the renovation type *Other Renovation Work* are summarised in Table 7.

Table 7 Advantages and disadvantages of using limit value 3: EPBT of the building renovation for Other Renovation Work

Limit value 2	Advant ages	Disadva ntages

	The effect of the energy retrofit is evident	Only possible for renovations which reduce energy consumption. Requires an energy-performance framework before and after renovation work (consider using data from the energy-rating labelling scheme). A short EPBT is not consistent with high CO_2 savings after 50 years. Possible solutions are governed by the building's energy benchmark.

4.4 Conversion

For *Conversion,* advantages and disadvantages are described for **limit value 2: benchmark for renovation of building component**, **limit value 4: EPBT of renovation of building-component**, **limit value 5: reference as benchmark for renovation,** and **limit value 6: comparing solutions** cf. Table 2.

If **Limit value 2** is applied, mapping is only required of the material quantities for 1 m^2 of building component. Energy consumption can be determined by using a simple thermal-loss calculation for the relevant building component.
For limit values at component level, it is not a requirement that the whole building performs well environmentally. Consequently, less environmentally harmful solutions will not offset the more harmful ones. This may narrow options for material choice and perhaps prevent certain solutions from being implemented. Further, it may prove difficult to accommodate renovation of buildings, subject, for example, to district plans or preservation orders, considered of architectural value, or have specific functional needs that must be solved, such as acoustics, lighting, fire, thermal mass, etc. However, it will be possible to combine this limit value with limit value 1, if the renovation work is extensive and comprises many building components.

If the scope for solutions and material choice is narrowed to any great extent, it may be a question of whether a renovation project is to go ahead, at all, rather than how renovation work could be carried out with a sensible choice of materials. This counteracts any incitement to renovate rather than demolish and rebuild.

The limit value provides an incentive to renovate the building component to achieve low thermal loss. However, building components could well have a relatively high thermal loss and still achieve large energy savings. By merely regarding the post-renovation thermal loss, consideration is not given to – whether or to which extent – the renovation has enhanced the building component. This is evident in eight examples of exterior wall conversion from the 29 renovation case studies in Figure 17. Limit value 2 will only include impact across the graph's x-axis. Here, the conversion of Dwelling, D6 will, with its high thermal-loss contribution, be regarded as the worst solution in terms of climate impact. Nevertheless, this is the solution resulting in the largest thermal-loss difference (below the x-axis) and hence a significant improvement of this particular exterior wall.

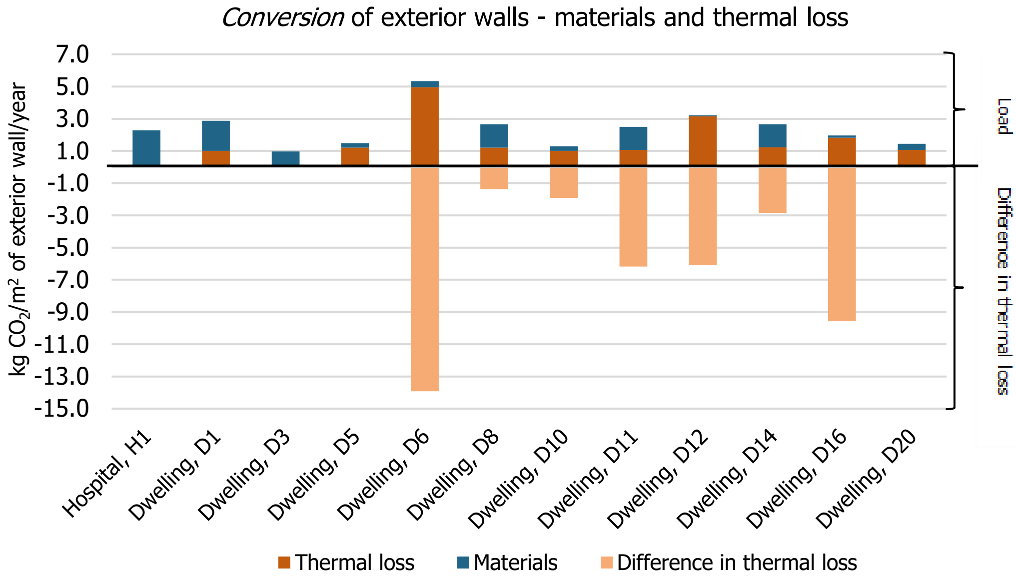


Figure 17 climate impact of the conversion of 1 m² of exterior wall in terms of both materials and thermal loss, and the change in thermal loss before and after conversion the exterior wall (pale orange bar). The consequences, when only considering the impact from the actual conversion, is represented by the orange and blue bars. Unlike this limit value, the limit value for environmental payback time (EPBT) addresses the difference in thermal loss

The outcome of this is that there may be differences in the material requirement in terms of energy efficiency for desirable or undesirable building components. Material requirements will vary if building components must meet identical energy requirements. This is illustrated in Figure 18, where roof constructions with different energy benchmarks are renovated according to the same U-value – it is evident that emissions from materials vary considerably. Besides the difference in energy benchmarks, it is also, in part, due to the specific construction and the insulation product selected for individual solutions.

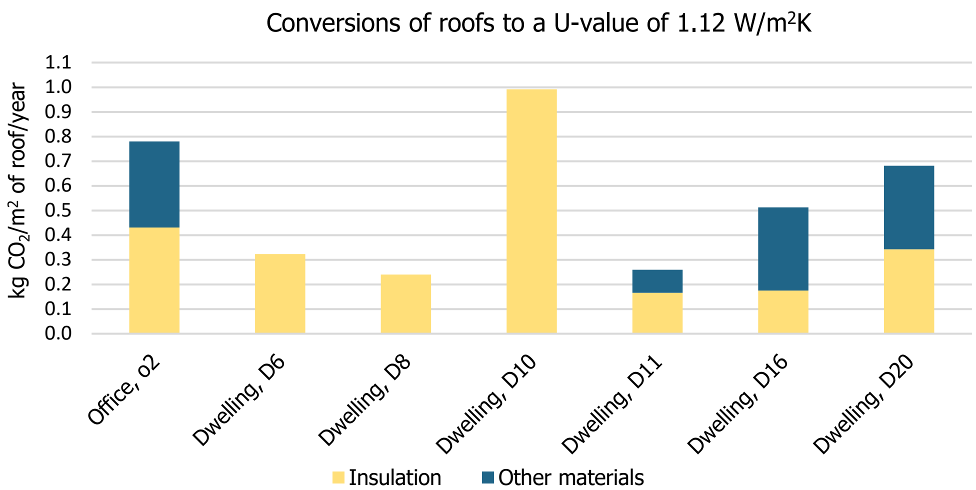
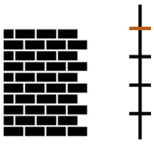


Figure 18 Seven roof constructions with different benchmarks renovated according to the U-value requirement for conversion work cf. BR18 section 279. The graph shows the environmental load from roof renovation projects broken down into insulation material and roof covering, if the latter has been replaced.

Advantages and disadvantages of limit value 2 for the renovation type *Conversion* are summarised in Table 8.

Table 8 Advantages and disadvantages of limit value 2 for the category Conversion

Limit value 2	Advantages	Disadvantages
	Mapping of material limited to 1 m² of building component. The requirement can be combined with limit value 1. Can be used for both building envelope and interior renovation work.	Less free choice of design because the limit value must be complied within the building component. Will be very similar to requirements for the environmental load of materials. It can be difficult to satisfy a limit value intended to embrace the same building component in different constructions. May result in reflections on *whether* to renovate rather than *how* best to renovate. No consideration given to whether the renovation has improved the building component environmentally. The need for cooling the building after re-insulation of building components, if relevant, is not included due to the calculation method.

Limit value 4 can only be used for building components that result in reduction of thermal loss. Figure 9 in section 3.1 shows that the renovation case studies Dwelling D4, D9, D12, D19 comprise conversion of building components without re-insulation and hence does not affect the energy consumption. Consequently, this limit value cannot be used in these cases.

As for limit value 2, the calculation only includes the environmental load of 1 m² of building component. This means that it is only necessary to document 1 m² of the material layer and prepare a simple thermal-loss calculation of the building component.

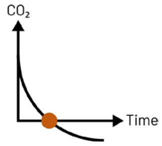
The environmental payback time will depend on the level of insulation of the existing structure. The worse the benchmark, the shorter the payback time (Balancepunkt (Point of Balance), Kai 2021)). In terms of limit values, this means that although the insulation level is the same for renovation work, it will be easier for a poorly insulated building component to comply with a limit value than an already insulated component.

Unlike limit value 2, EPBT will better illustrate the environmental improvement of renovating a building component and can be used as a communicative tool to advance energy-saving interventions.

Advantages and disadvantages of limit value 4 for the category *Conversion* are summarised in Table 9.

Table 9 Advantages and disadvantages of limit value 4 for the category Conversion

Limit value 4	Advantages	Disadvantages

	The mapping of materials is limited to 1 m² of building component and to new materials only. The energy saving can be documented via U-value calculations of 1 m² of building component before and after renovation. The limit value is better able to illustrate the effect of renovation.	Only applicable to renovation of building components resulting in a lower thermal loss. Existing conditions are significant – especially viable if the benchmark is poor. May lead to this becoming a material requirement, narrowing the options for material choice. A short EPBT is not consistent with CO_2 savings after 50 years.

Limit value 5 determines the reference based on the building's existing materials, i.e. it becomes possible to recreate the architectural expression from the facade material, for example.

The calculation can be made for 1 m² of building component and only include the materials that deviate from the specified LCA reference.

When conversion an exterior wall with a curtain wall, it is possible to build a new curtain wall or select material with lower environmental impact than the curtain wall. If the conversion needs to be made using materials corresponding to the LCA reference, no calculation will be necessary, since the LCA reference is a pre-accepted solution if it complies with the U-value requirement for conversion the building component.

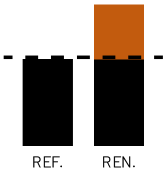
A free choice of materials is possible for facade cladding, for example, whose environmental load is greater than the LCA reference, providing that it is possible to add insulation to the structure to obtain a lower U-value to offset the extra environmental load.

When the LCA reference is specified from the original materials of the building component before renovation, the LCA reference will also change after the component has been remodelled. This might be an incentive to use materials with a lower environmental load, as the LCA reference will be affected, if a second conversion is required later in the building's lifetime.

Advantages and disadvantages of limit value 5 for the category *Conversion* are summarised in Table 10.

Table 10 Advantages and disadvantages of limit value 5 for the category Conversion

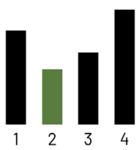
Limit value 5	Advantages	Disadvantages

	Mapping of materials is limited to 1 m^2 of building component. The calculation can be limited to the materials that deviate from the specified LCA reference. The materials used in the LCA-reference can also be used for the building component. Applicable to both building envelope and interior renovation work. No calculation is necessary if the conversion corresponds to the LCA reference – requirements for the conversion will be met. May provide free choice of materials with an environmental load higher than the LCA reference if offset by extra insulation to obtain a corresponding energy saving.	If materials are replaced by ones with a lower environmental load, the reference will be lower for later renovation work. Does not necessarily provide incentive to select materials with a lower environmental load than the original building component before renovation, the LCA reference.

Limit value 6 does not, as the only one, use a calculable benchmark, instead it specifies a requirement that variant analyses be made at building-component level. Within each separate building component – in the building envelope as well as in the interior structures – several solution proposals can be presented to enable selection of the materials with the least environmental impact.

Advantages and disadvantages of limit value 6 for the category *Conversion* are summarised in Table 11.

Table 11 Advantages and disadvantages of limit value 6 for the category Conversion

Limit value 6	Advantages	Disadvantages
	Can be used as a design parameter. No material mapping and an opportunity to increase focus on material choice as well challenging classic solutions. Any renovation work will comply with this requirement. Applicable to both building envelope and interior renovation.	It could prove an extensive exercise if many building components are to be remodelled. High-impact solutions can be implemented if the comparable variants have a high environmental impact.

4.5 Replacement

For *Replacement,* advantages and disadvantages are described for **limit value 2: benchmark for renovation of building component**, **limit value 4: EPBT of renovation of building-component, limit value 5: reference as benchmark for renovation,** and **limit value 6: comparison of solutions** cf. Table 2.

Advantages and disadvantages of limit values for Replacement correspond to those for additions dealt with in the previous section. One difference being that the whole building component is replaced, providing an opportunity to assess the component as newbuild using **Limit value 2.** However, no Danish limit values exist for building components, and it would be difficult to specify because of the wide span of functional needs. Figure 19 shows examples of impact from replacement of grade decks and exterior walls. In these examples, a great variation in the choice of other materials is evident, for example, facade cladding of exterior walls, whereas the variation in impact from ground floor slab is less, as the constructions tend to be more consistent.

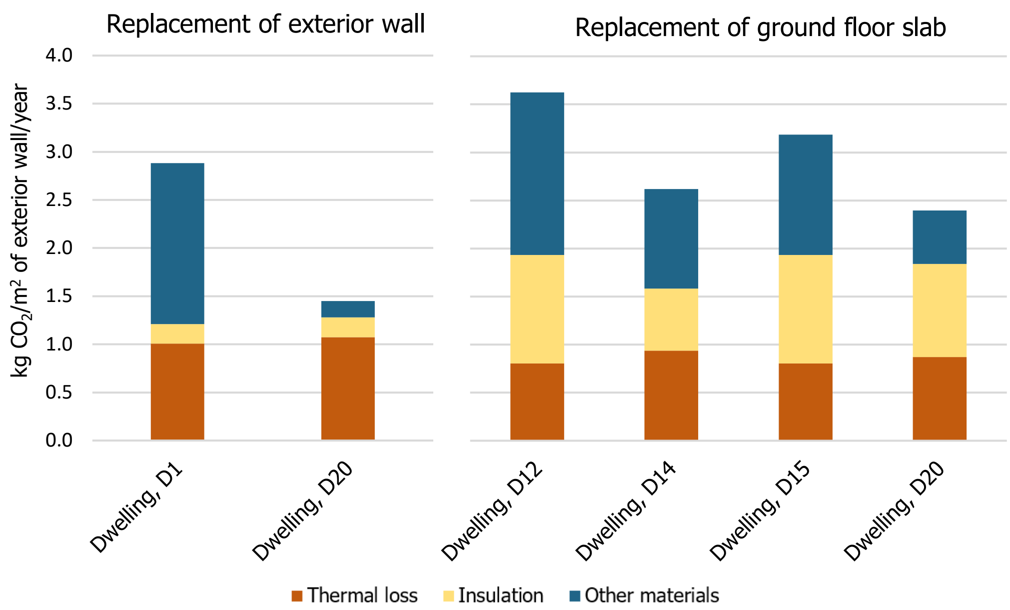
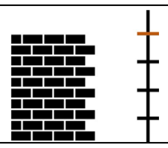


Figure 19 Total environmental impact from replacement of exterior wall (a) and replacement of ground floor slab (b)

Advantages and disadvantages of limit value 2 relative to the renovation type *Replacement* are summarised in Table 12.

Table 12 Advantages and disadvantages of limit value 2 for the category Replacement

Limit value 2	Advant ages	Disadva ntages
	Mapping of materials is limited to 1 m² of building component.	Less free choice of design because the limit value must be complied with for the building component

	The requirement can be combined with limit value 1. Applicable to both building envelope and interior renovation. A quality standard based on newbuild could be specified (reflecting, however, whether to demolish existing structures).	Will be very similar to requirements for the environmental load of materials. It can be difficult to satisfy a limit value intended to embrace the same building component in different constructions. The need for cooling the building after re-insulation of building components, if relevant, is not included due to the calculation method. Does not address the effect of the renovation on the overall building.

For **Limit values 4, 5, and 6**, the same advantages and disadvantages apply as those outlined for *Conversion.*

4.6 Structural alterations

The same applies to structural alterations as to replacement and conversion.

5 Economy and the climate

This section looks at the significance of the renovation requirements for the economy and the environment. A separate analysis framework has been applied to assess this. For this analysis, we do not use data from the case studies presented earlier in the report, as it would be a complex task to scale up nationally. Instead, we have used simple renovation scenarios based on data from the Danish BBR Building and Housing Register, estimated yearly rates of renovation work/replacement, typical constructions, etc. The calculations are illustrated in a spreadsheet accompanying this report.

Renovation requirements
In this section, we will also be looking at how future requirements can be drawn up. Please see section 7, where BUILD's recommendations concerning requirements are described in more detail. The recommendations include three types of requirements for CO_2 emission that can be selected when renovating buildings:

- Individual requirements for each of the renovated/replaced building components (along the lines of U-value requirements)
- Aggregate requirements to the renovated/replaced building components (along the lines of the heat-loss framework)
- Aggregate requirements to the building (along the lines of the energy-performance framework).

Additionally, BUILD recommends that requirements be set for LCA calculations at building level of CO_2eq/m²/year for Change of Use in existing buildings. Further, one could consider whether buildings undergoing deep renovation (transformation) should also be subject to requirements for LCA calculation at building level.

It is assumed that the requirements will initially be set for buildings with a heated floor space over 1,000 m².

5.1 Economic consequences

The estimated cost comprise only cost deriving directly from the requirements. Any voluntary initiatives encouraged by the requirements, or future requirements introduced later are not included.

Requirements for building components when renovating

We propose that individual requirements for building components subject to renovation/replacement be formulated so that using materials identical to those in the rain shield (for example red pantiles on a roof) and meeting the U-value requirements in the Building Regulations become a benchmark for the CO_2eq requirement for the building component. Selecting this will be sufficient to meet individual requirements for the building component.

There may be buildings where certain building components were renovated at an earlier date with a material other than the original one, for example a thatched or tiled roof replaced by steel or fibre-cement sheets. In such contexts, a dispensation application might be necessary if building permission is required for the renovation, and the problem is not handled generally by the code of practice.

If, when renovating/replacing a building component, a decision is made to use a different material for the rain shield, it will be necessary to do an LCA calculation to determine the CO_2eq/m²/year for the reference and the specific construction, respectively, to meet individual requirements for the building component. The time consumption for the two calculations is estimated at half a working day for the first component and a quarter working day for any further component calculations. The time consumption will not, for example, depend on the size or complexity of the building. In the long term, the time consumption will be reduced considerably or even disappear altogether by publishing a general catalogue of the CO_2eq/m²/year for typical constructions along the lines of *"Bygningsreglementets vejledning om efterisolering (Building Regulations Guidelines on Re-insulation"* (Danish Housing and Planning Authority, 2022).

The time consumption is estimated for the second year following the introduction of the requirement, when most start-up problems of handling the calculation would have been solved. For year 2, it is assumed that the time used to do the LCA calculation will be evenly distributed on a single person with expert knowledge of LCA calculations and an architectural technician. This follows the memorandum dated February 2022, "*Omkostninger ved krav i Bygningsreglementet til klimapåvirkning fra nye bygninger (Cost of Building Regulation Requirements for Environmental Impact from Newbuild*".

If we assume an hourly rate for architectural technicians of DKK 800 exclusive of VAT and DKK 1,100 exclusive of VAT for persons with expert knowledge of LCA calculations, the cost incurred for a building to be renovated will look like this:

DKK 3,600 plus VAT for buildings needing a calculation for 1 construction,

DKK 5,300 plus VAT for buildings needing a calculation for 2 constructions,

DKK 7,100 plus VAT for buildings needing a calculation for 3 constructions.

If the preferred construction with the preferred new rain-shield material fails to meet the requirement for CO_2eq/m²/year, further calculations may have to be made of alternative solutions until a solution that meets the requirement has been found. The assumption is that this will increase time consumption and cost by 50% and be necessary in half the renovation projects needing such a calculation.

Based on lifetimes and renovation rates for the various constructions in the building envelope in existing buildings, it is estimated that approx. 1,900 buildings over 1,000 m^2 are renovated annually with the renovation comprising one or more building components in the building envelope.
Further, it is estimated that in 63 of these buildings, roofs, exterior walls, and windows will be renovated, whereas in 600 of the buildings, 2 building components will be renovated/replaced, typically roofs and windows. In the rest of the buildings, only one building component will be renovated/replaced. In 40% of these, the roof will typically be renovated/replaced, whereas this will typically apply to windows in 60% of the cases.

If we assume that it will be necessary to make a calculation in three quarters of the buildings in which building components are renovated/replaced, in half of the buildings in which 2 building components are replaced, and in a quarter of the buildings in which only one building component is replaced, the annual cost of requirements for building components will total approx. DKK 3.8 million plus VAT.
The calculation is shown in the spreadsheet.

LCA calculation at building level

Time consumption and cost of LCA calculations at building level of CO_2eq/m²/year for existing buildings in the Change of Use category, and possibly for buildings undergoing deep renovation (transformation), are expected to resemble those for newbuild. See memorandum dated February 2022 *Omkostninger ved krav i Bygningsreglementet til klimapåvirkning fra nye bygninger (Cost of Building Regulation Requirements for Environmental Impact from Newbuild*). The premise for this assessment being that there will be significantly fewer building components and constructions in the LCA calculation, but conversely, an energy calculation for the building will have to be made following the renovation using the calculation program Be18.

For a building of 1,000 m², the cost will be DKK 42,400 less VAT, and for a building of 10,000 m², the figure is DKK 57,000 less VAT. The average size of buildings over 1,000 m² is 2,715 m² with an estimated cost of DKK 48,800 less VAT.

Unfortunately, the extent of changed use of buildings is not known, and it is not possible, therefore, to estimate the total cost of specifying LCA requirements at building level for this. Nevertheless, presumably the figure of changed use of buildings over 1,000 m² during a year will be minimal.

Nor is the figure known for buildings undergoing deep renovation (transformation), including renovation/replacement of one or more building components in the building envelope. If we assume that deep renovation comprises all the three building components roof, exterior wall, and windows, and LCA at building level becomes a requirement based on this, costs will amount to approx. DKK 3.1 million per year less VAT, inclusive of change of use and deep renovation of buildings. If the criterion is lowered to deep renovation only comprising two building components, costs will rise to approx. DKK 32.5 million per year less VAT. The calculation is shown in the spreadsheet.

5.2 Consequences for the climate

The following is an analysis of the significance of a Building Regulation renovation requirement from a climate perspective.

Method and assumptions

To determine the overall environmental effect of introducing LCA renovation requirements, the environmental impact from renovation projects is scaled up via the BBR Building and Housing Register and expected annual replacement rates. Data are used as follows:

- Emission from renovation projects (constructions/materials) come from LCAbyg 5 (BUILD, 2022) and is shown in the spreadsheet. Building site, foundations, technical installations, and domestic appliances do not figure in the calculations.
- The BBR Building and Housing Register has been used to determine the area of the building components being renovated. Here data were used for existing buildings constructed up to and including 2006. The building-component area was arrived at by means of a simplified geometric model, shown in the spreadsheet along with expected annual replacement rates. A breakdown of the building mass according to construction type has been applied consistent with registrations in the BBR Building and Housing Register for outside roof and exterior wall coverings.

Data and calculations are shown in the accompanying spreadsheet.

Findings

Based on the analysis, total greenhouse-gas emissions from materials used for renovation (exclusive of installations) are estimated at approx. 0.90 million tons CO_2eq per year for the entire building mass and 0.33 million tons CO_2eq per year for buildings over 1000 m^2 (the initial assumption being that requirements will be set for buildings over 1000 m^2). Figure 20 shows the distribution of greenhouse-gas emissions from materials used for renovation of buildings over 1,000 m². Exterior walls and roofs comprise approx. 16% (0.05 million tons CO_2eq per year) whereas windows comprise 27% (0.09 million tons CO_2eq per year).

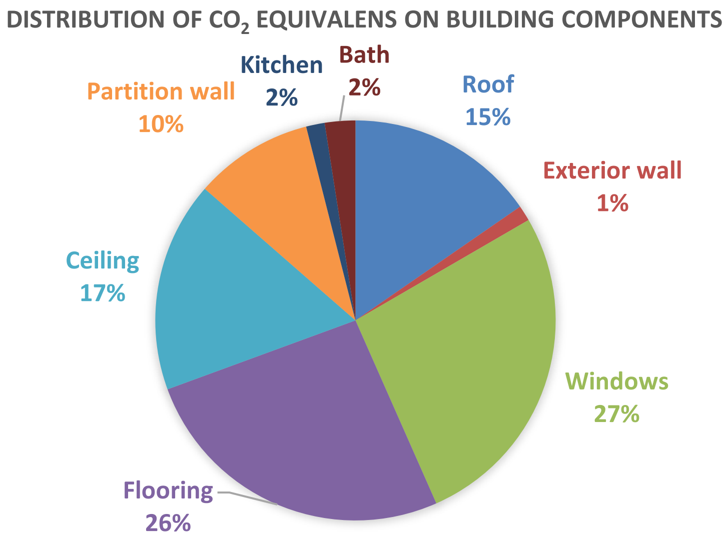


Figure 20 Distribution of environmental impact of renovation of buildings over 1,000 m² based on estimates and assumptions from the BBR Building and Housing Register, renovation rates of building components, and construction types. See the accompanying spreadsheet.

A renovation requirement for buildings over 1,000 m^2 will affect almost (0.05+0.09)/0.90 = 16% of total greenhouse-gas emissions from materials used for renovation. In comparison, the total emission of CO_2eq per year in *Klimastatus og -fremskrivning 2022 (Climate Status and Projections 2022)* amounts to approx. 45 million tons in 2020 (Danish Energy Agency, 2022), and a future renovation requirement for buildings over 1,000 m^2 will therefore affect approx. 0.3% of total emissions. If this requirement is introduced for all buildings regardless of size, the figure would be approx. 1%.
These findings are subject to some uncertainties associated with the assumptions outlined above.

6 Perspective

6.1 Risk of bypassing LCA requirements when renovating

It is a dilemma that the more and stricter requirements specified for renovation, the more obvious it will seem to demolish the building and build a new one. It is important, therefore, that requirements are as unambiguous, clear-cut, and easy to handle in practice as possible. The following lists some special focus areas concerning the LCA calculation method for operational energy use and materials, which may present problems in terms of compliance.

Operational energy use

If the renovation requirement for conversion building components is based on a method where the energy savings are offset in the CO_2 calculation for a given renovation project, there will be a risk that the insulation level of the existing construction is underestimated, showing a greater saving on operational energy than is, in fact, the case. It would be a good idea, therefore, to base the requirement (reference) on the minimum requirement for conversion cf. BR18 section 279.

Materials

There may be a risk of deliberately overestimating the LCA value of materials in the LCA calculation of the existing building component. Similarly, there may be a risk of underestimating the LCA value of materials in the LCA calculation of the new building component.
Materials disposed of will register negatively in the LCA calculation, carrying a risk of being forgotten or deliberately left out of the calculation.

6.2 LCA methodology for renovation work

As described in section 2.1, the LCA calculation of a renovation project complies with the European Standard EN 15978-1. This calculation method includes all activities and new materials resulting from the renovation, but consensus has yet to be reached on how existing building components should be treated in the calculation. It might be interesting, therefore, to investigate the environmental impact derived from existing materials when completing an LCA of a renovation project.

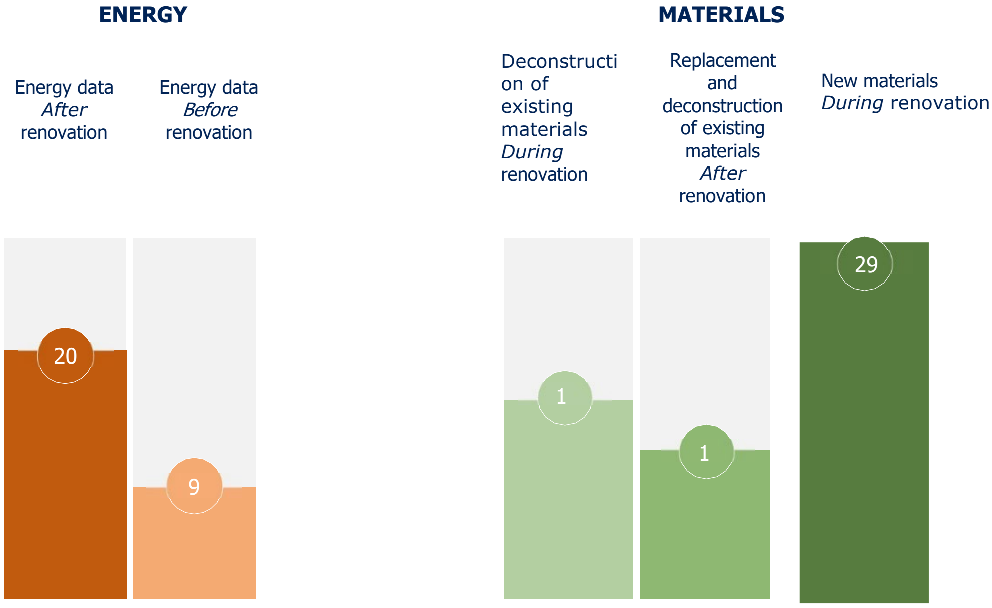
Existing materials can be subdivided into four categories: (1) the original production of the materials (already occurred); (2) deconstruction of materials during renovation; (3) replacement of materials after renovation (Use stage); and (4) deconstruction of materials at the end-of-life stage of the renovated building. Further, the energy consumption of the existing building might be relevant to look at depending on the limit-value method selected.

Access to data

Based on the 29 renovation case studies, we have investigated the significance of climate impact from existing materials. Initially, showing an overview of access to data in the existing building for each of the 29 case studies in terms of both energy use and materials, see Figure 21.

In the left-hand side of Figure 21, it is evident that, of the 29 renovation cases, an energy-performance calculation was made for the renovated building in 20 of these. Of these, it had been an integral part of the renovation projection work in 15 cases. The remaining five were prepared by BUILD, when sufficient data were available to set up a model. A pre-renovation energy-performance calculation had been made in only 9 renovation cases. In eight cases, this calculation was made by BUILD based on the available energy-rating label. In the ninth, an energy consumption calculation had been made by a consultant for the renovation project.

The right-hand side of Figure 21 shows the data availability broken down into materials for existing and new materials, respectively. In all 29 cases, it has been possible to include new materials used during renovation. In 16 of the cases, deconstruction of existing materials during renovation (category 2) are included. In only 12 cases were drawings and specifications available to enable mapping of all the existing materials retained in the buildings, either to be replaced during the process (category 3) or disposed of at the building's end-of-life stage (category 4).



Figures 21 – Available data

Contribution from existing materials in the building

Environmental load from existing materials is calculated using data from 9 renovation case studies.

The new materials are modelled in the same way as newbuild, including modules A1–A3, B4, C3, and C4. The existing deconstructed material is registered as End of Life, modules C3–C4. The existing materials retained in the building are modelled on the following assumptions:

- It is assumed that all retained supporting structures remain in the building during the entire reference study period, only counting as End of Life after 50 years, modules C3-C4.
- Building components/materials retained are replaced when obsolete cf. Levetidstabellen (Service life Table) (BUILD AAU, 2021b), modules B4 and C3–C4. The assumption is that this only applies to materials with a residual lifetime exceeding 5 years. If the residual lifetime is less than 5 years, it is assumed that the material is replaced after the number of years indicated in the Lifetime Table.

The result shown in Figure 22 shows the contribution made by new materials, deconstructed materials, and retained materials in the 9 case studies. Since biogenic materials release CO_2 when deconstructed, whether this is included in the calculation or not, may seriously influence results. Consequently, the result in Figure 22 is shown with and without release of biogenic carbon in modules C3–C4 for existing materials. Biogenic carbon is typically calculated as being neutral over the lifetime of the building, which could be an argument in favour of excluding it altogether.

Figure 22a shows that both the deconstructed and retained materials may result in high emissions compared with new materials. For example, in Dwellings, D9 and D13 they account for 70% and 66%, respectively. In this case, there are penalty points for both deconstructing and retaining biogenic materials such as timber structures in the building.

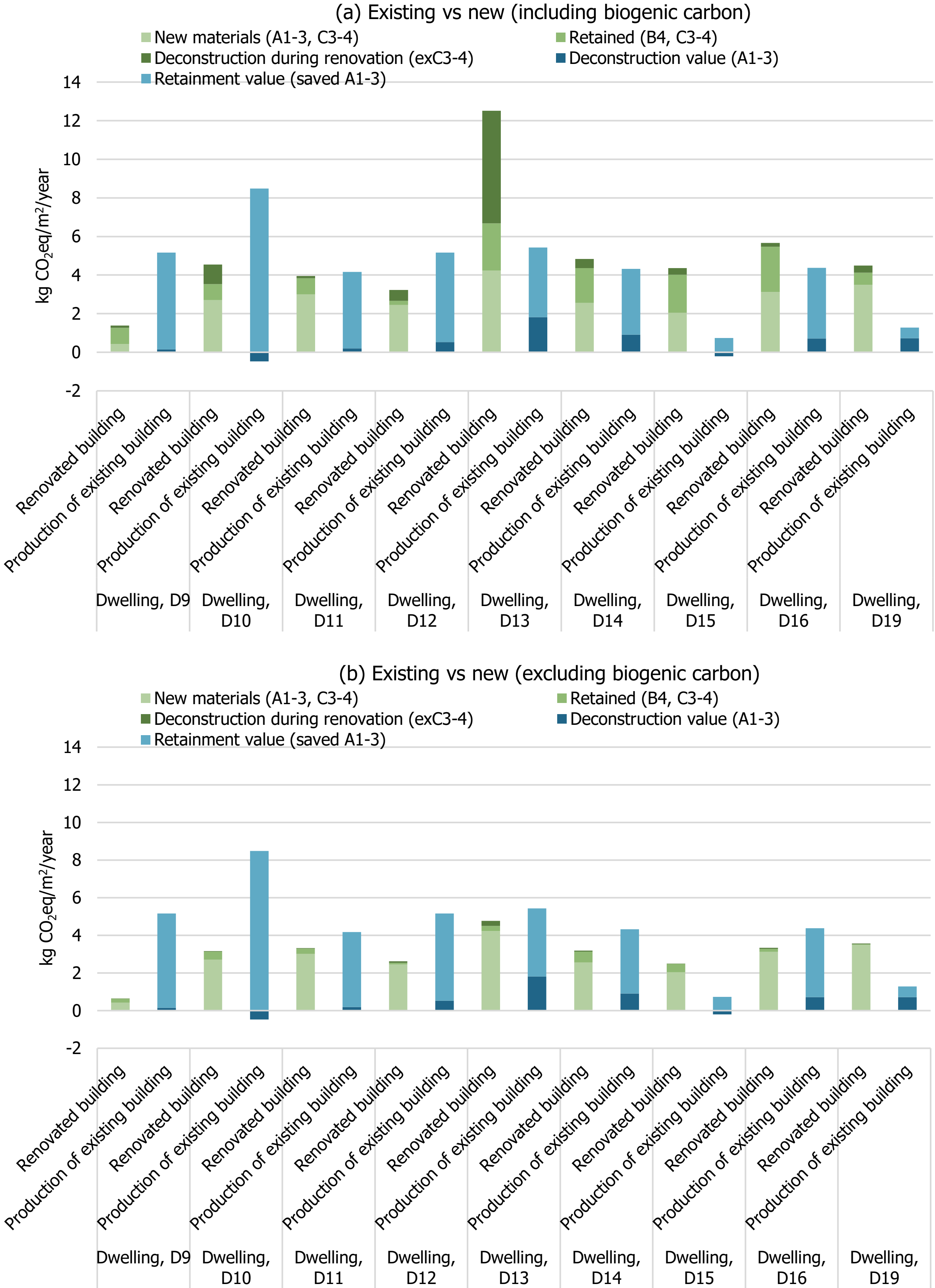


Figure 22 Environmental load from new and existing materials from 9 renovation case studies.

Instead, we could look at Figure 22b, where contributions from existing materials are significantly less. Notably for deconstructed materials during renovation, the graph shows a very small contribution of between 0.5–6% of the total impact from materials. Contributions from retained materials in Figure 22b will also decrease when released biogenic carbon is left out of the calculation.

However, the graph shows that retained materials in some cases may comprise 34% of total impact from materials (Dwelling, D9). Retained materials are also of some significance to D10, D14, and D15, contributing 14%, 18%, and 17%, respectively.

Value of existing materials

To promote environmentally sound renovation where the maximum amount of material is retained in the buildings, existing materials must also be regarded as a valuable part of the building. They contain captured CO_2 from the original material production when the building was erected (category 1). Again, the value of existing materials can be compared with those demolished/disposed of during renovation and those retained, see Figure 23.

Figure 23 shows the climate impact from new and existing materials during and after renovation (also shown in Figure 23b) and the embedded environmental load, the "value", of the existing materials (grey colours). It is evident from the cases that the great majority of the embedded impact is retained in the building when renovating.

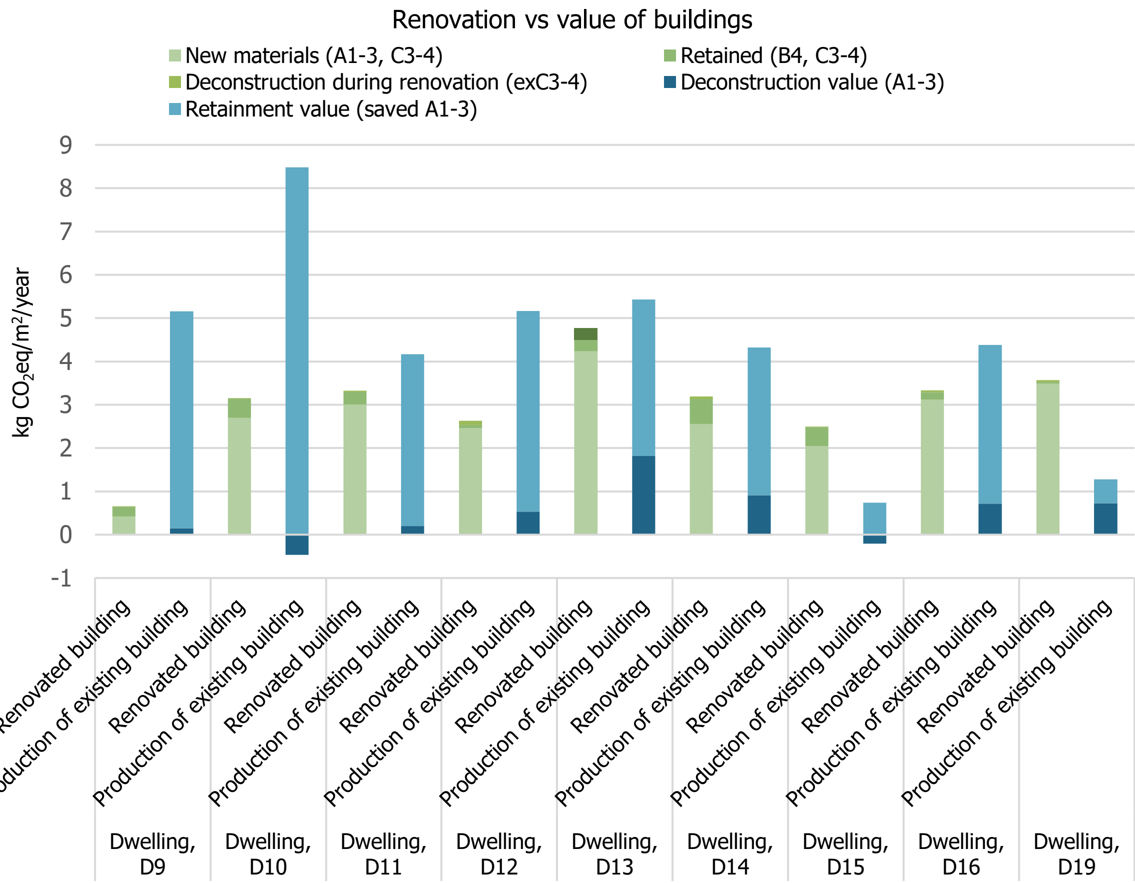


Figure 23 Material contributions from new and existing materials vs embedded CO_2, value of existing materials (Production A1–3).

6.3 Emission factor developments

Determining total future potential CO_2 savings from renovating the building mass is a complex affair, since developments in heat conversion in buildings away from fossil fuels will rise significantly over the next years. Further, renewable energy systems will become widespread. Determining the potential would therefore be highly influenced by the benchmark year used. Figure 24 shows a projection of the CO_2 emission factor for electricity, district heating, and piped gas until 2035 based on *Klimastatus og fremskrivning 2022 (Climate Status and Projections 2022)* (Danish Energy Agency, 2022).
.

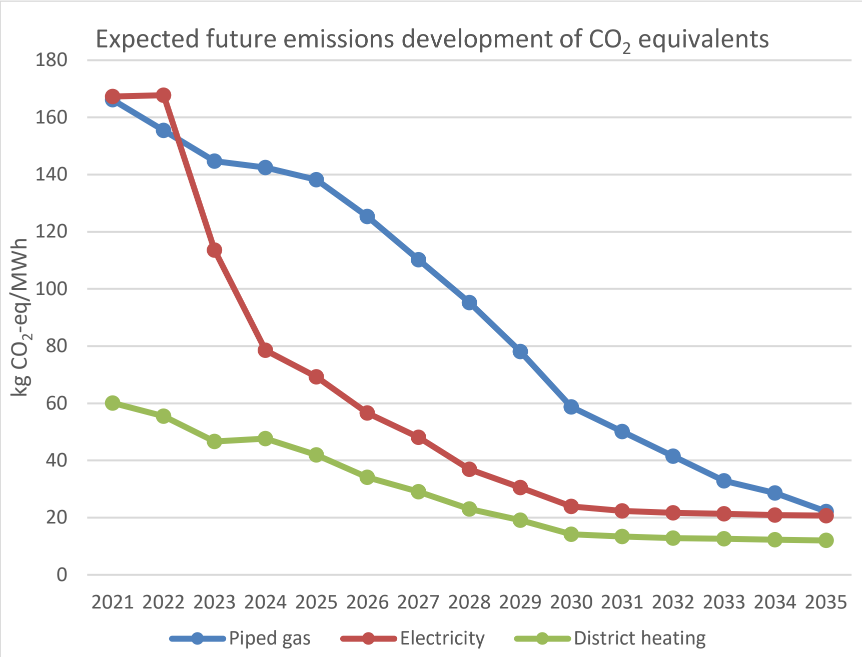


Figure 24 Expected CO_2 emission-factor projection for piped gas, electricity, and district heating based on (Danish Energy Agency, 2022)

Several years are likely to pass before any LCA renovation requirements are fully implemented in the Building Regulations, while it is evident from the projection of emission factors in Figure 24 that these will be vastly reduced compared with 2022 levels. The significance of operational energy is expected to dwindle considerably over the next few years, thus increasing EPBT in tandem with impact from materials rising proportionately. It might be considered, therefore, whether an LCA renovation requirement should be solely based on a material requirement.

7 Recommendations

7.1 Three general recommendations for renovation requirements

For future requirements for LCA of renovation work, it makes sense to apply and retain 2018 Building Regulation definitions to the greatest extent possible. The table below shows the relationship between the present energy requirements and recommendations for LCA requirements. We recommend using limit value 1 for an "LCA framework" and limit value 5 for an "LCA component requirement/framework", see Table 13.

As with the energy requirements, it makes no sense to specify requirements for LCA of minor maintenance and repair work, and LCA requirements will therefore exclusively be relevant for *Conversion*, *Replacement*, and *Change of Use*.

Table 13 Recommendations for LCA requirements and their relation to energy requirements. Limit values 1 and 5 are used to meet the LCA framework and LCA component framework/requirements

	Renovation type	Energy requirements	LCA requirements
Building level	Additions	Energy-performance framework (for the actual addition) Heat-loss framework Component requirements	LCA framework
	Change of use	Energy-perfomance framework Heat-loss framework Component requirements	LCA framework LCA component framework LCA component requirements
	Other renovation work		LCA framework LCA component framework LCA component requirements
Building-component level	Replacing building parts	Component requirements	LCA component requirements
	Conversion	Component requirements	LCA component requirements
	Structural alterations	Component requirements Heat-loss framework	-
	Repairs	-	-

1. LCA requirements for renovation work

For all renovations over 1,000 m^2, a limit value could be observed at either building or building-component level. This gives the option of meeting the limit value for simple renovation work (one or few building components) via requirements to building components, whereas for deeper renovation work, the renovation could be considered an entity, for example, if some building components are required to compensate for others.

If, for renovation work, renovation requirements will be met at building level, these should match the requirements to newbuild.

Further, a requirement for all renovation work under 1,000 m^2 could stipulate that a calculation be made either at building-component or building level without the need to comply with a limit value. This will help to educate even small actors within the sector, who will then be able to adjust to this requirement in future.

2. LCA requirements for additions

Additions could comply with the same requirements as LCA of newbuild. Initially, this could apply to additions over 1,000 m². Alternatively, requirements could be set for additions down to 500 m².

3. Special LCA requirements for deep renovation work

In buildings (over 1,000 m²) undergoing deep renovation, there could be a requirement for an LCA to be made at building level. If a decision has been made to meet requirements for building components, a calculation must also be made at building level due to this supplementary requirement – which need not be compared with a BR limit value at building level. This requirement is specified to motivate and educate/develop the sector. The calculations may provide data to be used in evolving the provisions further.

Guidelines for requirements at building-component level

LCA requirements for conversion and replacement of building components (limit value 5)

This requirement is met by documenting that the specific total environmental impact from a building component is less than a specifically calculated LCA reference value, see Table 14. This requirement is based on limit value 5. In Annex I, a calculation example for limit value 5 is outlined.

Table 14 Description of LCA requirements for conversion and replacement

LCA reference value equals the calculated sum of kg CO_2eq/m² of the existing building component.	*Specific building component in project* equals the calculated sum of kg CO_2eq/m² of a renovated building part.
The U-value level from BR (conversion and change-of-use requirement, respectively). CO_2 emissions from materials added to make an identical construction (inclusive of insulation layer in accordance with conversion requirement). Reference to be calculated using generic data from LCAbyg.	U-value level assumed met. CO_2 emission from the materials added to the building component. Project to be calculated using generic data from LCAbyg. Alternatively, environmental data from product-specific EPD can be used.

In an attempt at making the requirement operational, we recommend that a catalogue of pre-accepted solutions matching *Bygningsreglementets vejledning om efterisolering (Building Regulation Guidelines on Re-Insulation) (Danish Housing and Planning Authority, 2022)* be gradually made to act as LCA reference. This will avoid having to document the environmental load of the LCA reference for every project. Pre-accepted solutions should be evolved for different construction principles within each building component.

Possibilities of assessing all building components together

For renovation work affecting more than one building component, the LCA calculation can be summarised, and, in principle, surplus/shortage from the calculations be transferred between individual building parts (for example, a shortage of 2 kg CO_2eq from renovation of the roof construction can be compensated for by a surplus of 2 kg CO_2eq from renovation of the exterior wall). An LCA component framework is established by adding LCA reference values multiplied with the specific areas.

The calculation of environmental load from LCA of building components from the actual building must thus be less than the LCA component framework. Using an LCA component framework is an incentive to reuse or improve material choice in some building components, enabling the gain to be transferred to other building components.

Calculation assumptions

All calculations are based on a specific type of heating utility in terms of emission factors, and both the reference and project are based on the heating source expected to be installed in the building after the renovation is complete.

Generic material values are applied in all calculations relating to the reference. When calculating the specific project, material values from specific materials (EPDs) are used, and they must accompany the calculations as documentation for the performance of the individual materials.

Limitations

- Only applicable to conversion and replacement.
- Exceptions may be made due to the complexity of structural alterations. For example, installing new lifts in a stairwell requiring structural alterations of the floor and roof. Alternatively, the requirement could also be met at building level.
- Applies to building envelope building components, only.
- Does not apply to technical installations or windows.
- For replacement, the reference still applies to a whole construction corresponding to BR energy requirements. This means that the calculation only concerns extra insulation, cladding, and possibly substructures for extra insulation. In older buildings where building components are installed according to obsolete principles, such as a grade deck consisting only of soil/clay, dispensation could be given to replace it with a new construction of concrete and pressure resistant insulation, for example.
- LCA reference requirements for windows and doors may be difficult to meet, since new windows with wood/aluminium frames/casements may have a higher environmental impact than older windows with frames/casements of pure wood. They should therefore not be subject to the requirement at present. Instead, an LCA labelling scheme should be developed for windows. Alternatively, the LCA reference, in each case, could be a wood/aluminium frame/casement, corresponding to today's commonly used solutions.
- Environmental data for installations are limited and the basis for an LCA reference therefore unreliable. Initially, the requirement can be met based on applicable energy requirements.

Guidelines for requirements at building level

LCA requirements for renovation work at building level (Limit Value 5)

According to the LCA method in section 3.1, a full-scale LCA must be made. The requirement is based on limit value 1.

7.2 Recommendation for extended data sets

As evident from Figure 9, the 29 case studies comprise major renovation work involving a series of changes to the building. As a result, only a limited range of renovation work is analysed. A larger data set is needed to cover both minor and major renovation projects to evolve more well-founded methods embracing the differences evident in renovation and conversion of existing buildings in Denmark. A more comprehensive representation of renovation work should, to a greater extent, include the renovation work typically carried out. This can be rectified by obtaining more cases involving small buildings, especially single-family housing, which constitute a significant share of the overall building mass.

Apart from data from more typical renovation work, it is also important to learn more about renovation work in the category of *Change of Use* – only represented by 4 cases and may vary considerably in impact from materials as demonstrated in Figure 13. However, it is necessary to determine how *Change of Use* should be ultimately defined in a future LCA requirement, if we are to gradually abandon present energy requirement definitions.

More cases would also provide a more substantial data set from which to assess renovation requirement effects on the environment. The environmental effect assessed in section 5 is determined on simplified assumptions. Using a larger number of cases more representative of the Danish building mass could result in a fairer view of the potential.

To structure a future process for obtaining data, it would be a good idea to use a roadmap to map the necessary steps towards making the data collection broader. Mapping which case types to target and which data are necessary to make the required LCA.

7.3 Recommendation for developing renovation categories for LCA requirements

Renovation cases under ”Other Renovation Work” comprise a sizeable span of renovation work and different purposes, such as energy optimisation, interior renovation, and change of function. Since this category include the greater part of the cases, 23 of a total of 29, we recommend further developing definitions for renovation categories that increasingly address future LCA requirements for renovation work, thus enabling the handling of the many and considerable differences.

The report introduces the category ”Deep Renovation Work” as an option to separate minor and major renovation projects. However, all 29 cases treated in this report would readily fit into this category, and it might therefore be necessary to subdivide/separating out cases even further.

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9 Annex I

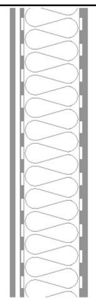
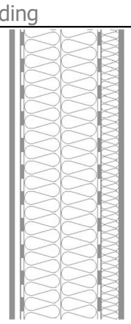
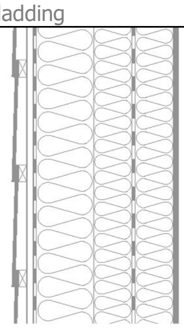
Example of LCA requirements for conversion and replacing building components

Two examples of how limit value 5 could be defined as an LCA requirement are presented here. These are merely two suggestions for working with the idea of an LCA reference, and it is an invitation to further develop this method.

In the following two examples, a renovation calculation is made for a building, where the roof and exterior wall are remodelled and the grade deck replaced. A reference situation is defined for all building components based on the existing construction. The reference is considered the solution which, for renovation, meets the component requirement for the U-value for renovation cf. BR sections 250–256. Here pre-accepted solutions, evident from the *Building Regulation Guidelines on Re-Insulation* can be used (Energy Consumption (sections 250–298)).

Example #1: The LCA reference forms the basis for the pre-accepted solution – for the "project", only materials that deviate from the reference need be included in the calculation.

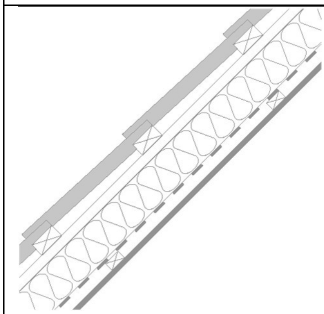
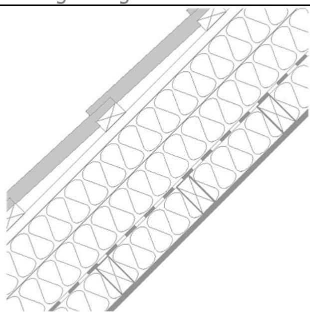
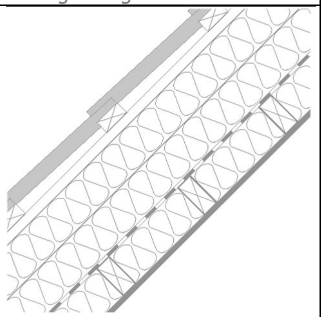
This example illustrates how to set up a simple calculation, where only materials that deviate from the reference are included in the calculation. All layers in a construction which comply with the reference are thus pre-accepted and will be permitted without the need for a calculation to support documentation.

<table>
<tr><td colspan="3">Eksempel #1.1 Constructing a lightweight exterior wall</td></tr>
<tr><td colspan="3">The exterior wall is a lightweight construction with an exterior timber facing. The reference for this conversion project is therefore a re-insulated timber-clad exterior wall that meets the component requirement of 0.18 W/m²K which corresponds to an insulation thickness of 250 mm according to the guidelines mentioned earlier.</td></tr>
<tr><td>Before renovation</td><td>Reference
U = 0.18 [W/m²K]</td><td>The
project</td></tr>
<tr><td>Timber facade
Vented cavity space
Wind barrier
Insulation thickness ≤ 150 mm
Vapour barrier
Wall facing</td><td>Timber facade
Vented cavity space
Wind barrier
Re-insulation thickness 200 mm
Vapour barrier
Re-insulation thickness 50 mm
Wall cladding</td><td>Slate facade
Vented cavity space
Wind barrier
Re-insulation thickness 200 mm
Vapour barrier
Re-insulation thickness 50 mm
Wall cladding</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Source: (Danish Housing and Planning Authority, 2022)

In this example, the existing exterior timber facing needs to be replaced by slate. Slate is a material with a higher environmental load than timber, and this added environmental load must be compensated for by adding more insulation, for example. Therefore, 100 mm mineral wool is added to the exterior wall. This requires extra spacer bars, which are also included in the environmental balance sheet for the *Project*.

	LCA reference		Project	
Share of CO_2 emissions	Material	kg CO_2eq/ m^2	Material	kg CO_2eq/ m^2
Extra insulation			100 mm mineral wool	4.14
Extra construction			Timber posts	2.16
Facing	Timber boards inclusive of battens and fixings	12.80	Slate facade inclusive of battens and fixings	19.8
Energy saving from extra insulation			U-value = 0.13 W/m 2 K	-17.56
Balance		**12.80**	≥	**8.54**
LCA component requirement complied with				**YES**

Example #1.2: Conversion sloping roof		
The roof is a sloping construction with roof tiles. The reference for this conversion project is therefore a re-insulated roof with roof tiles, which meets the component requirement of 0.12 W/m²K, corresponding to an insulation thickness of 300 mm according to the guidelines mentioned earlier.		
Before renovation	Reference U-value = 0.12 [W/m²K]	Project
Roof tiles on battens Insulation thickness ≤ 100 mm Vapour barrier Ceiling facing	Roof tiles on battens Re-insulation thickness 200 mm Vapour barrier Re-insulation thickness 100 mm Ceiling facing	Roof tiles on battens Re-insulation thickness 200 mm Vapour barrier Re-insulation thickness 100 mm Ceiling facing
		

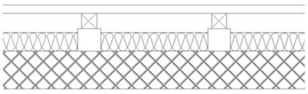
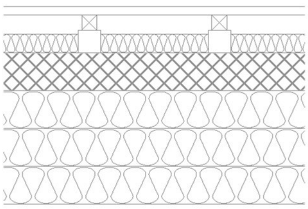
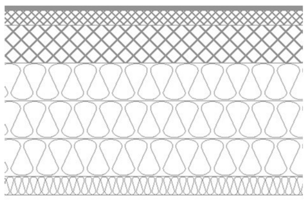
Source: (Danish Housing and Planning Authority, 2022)

In this renovation project, the roof tiles were reused, as they had not yet reached the end-of-life stage. Thus, environmental load from new roof tiles was avoided whilst the reference construction was met.

	LCA reference		Project	
Share of CO_2 emissions	Material	kg CO_2eq/ m^2	Material	kg CO_2eq/ m^2
Extra insulation			None	
Extra construction			None	
Facing	Roof tiles including battens and fixings	19.3	Reusing roof tiles – new battens and fixings	3.14*
Energy saving via extra insulation			None	

Balance		**19.3**	≥	**3.14**
LCA component requirement complied with				**YES**

*Only environmental load from new battens and fixings are calculated, as the roof tiles were reused

Example #1.3: Replacing grade deck		
The grade deck comprises a concrete deck facing the soil with a wooden floor on stickers. The reference for this conversion project is therefore a new grade deck, which meets the component requirement of 0.10 W/m²K, corresponding to an insulation thickness of 350 mm according to the guidelines mentioned earlier.		
Before renovation	Reference U = 0.10 [W/m²K]	Project
Floor on stickers Insulation thickness ≤ 50 mm Concrete deck	Floor on stickers Insulation thickness ≤ 50 mm Concrete deck Insulation 350 mm	Linoleum flooring 50 mm screed Concrete deck Re-insulation thickness 300 mm Re-insulation thickness 50 mm (pressure resistant)
		

Source: (Danish Housing and Planning Authority, 2022)

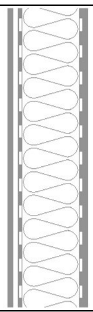
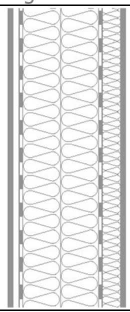
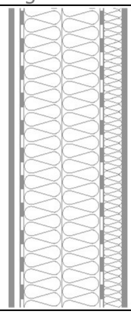
When replacing the grade deck, the flooring was changed from timber to linoleum (note that this is not reflected in the drawing!). The reference has thus been exceeded and it will be necessary to add extra insulation under the concrete deck, counting as further environmental impact over and above the reference. Replacing the grade deck is one example, where it proves impossible to comply with the LCA component requirement. This replacement could have met the reference requirement if wooden flooring on stickers had been chosen instead.

	LCA reference		Project	
Share of CO_2 emissions	Material	kg CO_2eq/ m²	Material	kg CO_2eq/ m²
Extra insulation			50 mm EPS	5.74
Extra construction			None	
Floor construction	Wooden flooring on stickers	5.92	Linoleum on screed	20.7
Energy saving when adding extra insulation			U-value = 0.09 W/m²K	-3.94
Balance		**5.92**	≥	**22.5**
LCA component requirement complied with				**NO**

Example #2: The LCA reference is a calculation of all the layers removed and replaced in the building component – in the ”project”, calculations must be made of all added layers.

This is an example of a calculation where all the materials removed are included in the calculation. Thus, it is possible to optimise all layers of material and select materials that perform better than the reference. A calculation example of conversion an exterior wall is given here.

#2.1 Constructing a lightweight exterior wall

<table>
<tr><td colspan="3">The exterior wall is a lightweight construction with exterior timber facing. The reference for this conversion project is therefore a re-insulated timber-clad exterior wall, which meets the component requirement of 0.18 W/m²K, corresponding to an insulation thickness of 250 mm according to the guidelines mentioned earlier.</td></tr>
<tr><td>Before renovation</td><td>Reference
U = 0.18 [W/m²K]</td><td>Project</td></tr>
<tr><td>Timber facade
Vented cavity space
Wind barrier
Insulation thickness ≤ 150 mm
Vapour barrier
Wall facing</td><td>Timber facade
Vented cavity space
Wind barrier
Re-insulation thickness 200 mm
Vapour barrier
Re-insulation thickness 50 mm
Wall cladding</td><td>Timber facade
Vented cavity space
Wind barrier
Re-insulation thickness 200 mm
Vapour barrier
Re-insulation thickness 50 mm
Wall cladding</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Source: (Danish Housing and Planning Authority, 2022)

This example is based on #1.1, where the same facade type is constructed once again. The exterior wall is therefore insulated and new timber facing installed. Because of the re-insulation layer, the vapour barrier is moved 1/3 into the insulation layer. Further, the interior cladding is removed. In this project, wood-fibre insulation had been specified.

	LCA reference		Project	
Share of CO_2 emissions	Material	kg CO_2eq/ m^2	Material	kg CO_2eq/ m^2
Insulation	250 mm mineral wool	10.35	250 mm wood-fibre insulation	6.80
Construction	Extra timber frame Vapour barrier	7.32	Extra timber frame Vapour barrier	7.32
Inside cladding	Two layers of gypsum boards	2.98	Two layers of gypsum boards	2.98
Facing	Timber boards inclusive of battens and fixings	12.80	Timber boards inclusive of battens and fixings	12.80
Balance		**33.45**	≥	**29.9**
LCA component requirement complied with				**YES**

Possibilities of assessing all building components together

For renovation work comprising more than one building component, the LCA calculations can be added and, in principle, surplus/shortage from the calculations be transferred between individual building parts (for example, a shortage of 2 kg CO_2eq from renovation of the roof construction be compensated for by a surplus of 2 kg CO_2eq from renovation of the exterior wall). An LCA component framework is established by adding LCA reference values multiplied with the specific areas.

The calculation of environmental load from LCA of building components from the actual building must thus be less than the LCA component framework. Using an LCA component framework is an incentive to reuse or improve material choice in some building components, enabling the gain to be transferred to other building components.

Example of LCA component framework (continued from example #1 above)

The examples above show that the LCA requirement cannot be met in respect of the grade deck, whereas both the exterior wall and roof conversion are below the requirement. Based on exterior wall, roof, and grade deck areas from a case-study building, the findings are scaled up as shown in the table below. If the renovation of the three building components are viewed collectively, the LCA component framework will be complied with, as the overall renovation work results in a lower environmental impact than the sum of the reference values.

	Area	LCA referece	LCA reference x area	LCA project	LCA project x area
	[m^2]	kg CO_2eq/m^2	kg CO_2eq	kg CO_2eq/m^2	kg CO2eq
Exterior walls	531	12.8	6,797	8.54	4,535
Roof	682	18.6	12,685	3.14	2,141
Grade deck	534	5.92	3,161	22.5	12,015
SUM			**22,643**	≥	**18,691**
LCA component framework complied with					**YES**

10 Annex II:

As part of the project and in an effort to prepare tangible limit values which provide an incentive to renovate, we have specifically aimed to make use of knowledge and experience from the construction sector. This was done via two meetings with a carefully selected group of experts comprising persons in trade organisations and private firms of consultants. Points, perspectives, and input from the two meetings are summarised as general topics/themes.

Workshop 1 – Introduction to methods and categorisation of renovation types The main concerns of the discussion were: when to specify requirements and how to differentiate between renovation types and stakeholders' competences, large-scale projects vs private home owners.
Which kind of renovation should a limit value promote? • Which type of renovation work is necessary to undertake in respect of our existing building mass? Deep renovation work? To determine this is imperative. • Consideration must be given to renovation work which result in energy savings and that which do not – merely resulting in environmental load. • Do not forget the users of the building – renovation work should also further functional and social aspects. • What will the effect of regulation be? – Compliance with rules and requirements.
When must an LCA requirement be complied with? • How many and which interventions should trigger an LCA requirement? • A future requirement must be adapted to accommodate both small and large stakeholders
Possibility of meeting requirements at building and building-component level • One could start with a component requirement at a certain level – transferring it to building level if several interventions are carried out. • Various stakeholders with varying levels of competence, such as home owners, should be able to comply with the requirements. • Requirements can be specified based on the building's area – renovation projects of large buildings often require a high level of competence and *vice versa*. • Area subdivision – stakeholders with multiple competences are used in buildings with extensive areas. • Allowing for small stakeholders, such as home owners.
(How) To register operational energy consumption? • It can be difficult to specify a common requirement when energy is converted into CO_2 – should the measurement unit instead be kWh? • The benchmark could be the energy-rating label – also for documenting potential energy savings. • Could be problematic to use the standardised emission factors for district heating – instead taking into account local emission factors.

Workshop 2 – Introduction to recommendation for limit values and further work Main points of the discussion: feedback on calculation method for limit value 5 and how to extend the data set.
Feedback limit value 5 – benchmark • All layers of material in a building component should be looked at, including insulation, both for the ”LCA reference” and the ”project” itself. If insulation is left out, this may be an incentive to use other insulation types than mineral wool, such as wood-fibre or cellulose. • For the calculation, it is important to look at everything being removed from the construction and replaced. In this way, the LCA reference will also depend on the type of renovation intervention, for example, in an exterior wall – is renovation work done from the inside or outside? • The U-value, and hence the energy, should be removed from this LCA requirement – we assume that the U-value requirement is met cf. the energy requirement. Consequently, the calculation will only concern materials. • An LCA reference could be a good solution to a requirement. In the long term, a pre-accepted catalogue of benchmark values could be compiled for different construction types. This would take into account the various construction principles, timber frames vs a brick-built facade, etc.
Building or building-component level? • Based on a full-scale LCA, a renovation project should be viewed as a whole. In the process, requirements could be specified for studies of variants, where the best materials will be incorporated in the full-scale LCA. • Requirements for the building envelope should be separated from other building components. It would be a good idea first to specify requirements for the building envelope. Later, requirements for building components not affecting operational energy use could be prepared.
Renovation categories for LCA requirements • Deep renovation – focusing on the present definition addressing energy optimisation and closely associated with the building envelope. • Interior conversion. • Transformation (change of use – change of function). • Renovation work can be defined based on the number of layers in the building being renovated, for example, one layer for the building envelope, one for installations, one for interior walls, etc. The more layers, the bigger the renovation project.
Extending the data set • It will not be possible to obtain data for renovation work until a requirement for renovation work is introduced – particularly when collecting data for single-family housing. • It is difficult to set a limit value before having gained access to data – a requirement could therefore be that an LCA be made. • A requirement for making an LCA must be meaningful – there should be a limit value to be complied with at the same time – a motivating factor to make the calculation. It is essential that contractors consider it meaningful to make an LCA. A limit value could therefore initially be simple and easy to comply with for the purpose of generating more full-scale LCAs. • More attention should be paid to the most general renovation work – particularly based on single-family housing, which constitute a major part of the building mass. A future requirement should therefore initially focus on handling typical renovation work.

• The sector is showing interest in being actively involved in developing more cases – it is important to determine what kind of data are required.
Incentives for renovation • It should not be a complex affair to comply with and document an LCA requirement. • Specific emphasis should be on making it as simple as possible. • Emphasis on extending the lifetime of the building – there must be an incentive to preserve. • Could it cause problems if renovation was staggered to facilitate complying with a specific LCA requirement? • It is difficult to include bypassing of rules as a factor for introducing requirements – far more important to see a requirement through and then regulate it later to mitigate any errors and omissions.

Whole Life Carbon Assessment of Renovation

The purpose of this project is to analyse the possibility of specifying requirements for the environmental impact of renovation work, where both the requirement and methodology must be operational and aim towards reduced CO_2 emissions. This is done via a systematic combination of renovation types and limit values, exemplified via collected renovation projects.