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CONTENT

PREFACE

From January 2023, based on the political agreement on the National Strategy for Sustainable Construction, requirements for the climate impact of buildings were introduced in Denmark. According to the strategy, the level of ambition must be adjusted and tightened every two years - 2025, 2027, 2029.

Currently, the lifecycle scope included in the building regulation covers the product stage (A1-3), the replacements (B4) and parts of the end-of-life stage (C3-4) of buildings. The Danish Social And Housing Authority has asked BUILD to investigate the climate consequences of, and possibilities for including new stages and modules in the future requirement for climate impact of buildings. In this report, this has been seen in relation to the expected climate effect, availability of data and workload associated with the calculation of the modules that have been omitted in the 2023 requirement.

The project intends to support decisions for the upcoming adjustments to the requirement for buildings' climate impact, as well as be used as input for the development of future limit values.

BUILD – Department of the Built Environment
Division for Energy and Sustainability in Construction

Tine Steen Larsen
Head of Division

SUMMARY

A building's life cycle assessment (LCA) consists of different stages, which are divided into modules according to the European standard EN 15978. Modules describe the impacts of the different processes to be included in the assessment.

As a response to the urgent state of climate change and the need for action without further delay, several countries in Europe have introduced, or are in the process of introducing, whole life assessments and limit values into their regulations. The life cycle scope considered in the methodology of each country differs – Netherlands and France cover a wider scope and require whole life cycle assessments, while other countries like Sweden have a narrower scope that is limited to upfront carbon emissions from production (A1-3) and construction processes (A4-5).

In the case of Denmark, due to limited data, not all modules are included in the requirement for the climate impact of buildings, which was introduced as of 1 January 2023 in the Building Regulations. Currently, the lifecycle scope included in the building regulation covers the product stage (A1-3), the replacements (B4), operational energy use (B6) and parts of the end-of-life stage (C3-4) of buildings. Module D must be reported separately.

In principle, to ensure as accurate calculations as possible, as many modules as possible should be included in the scope of future limit values, and with as high a level of detail as possible. By expanding the climate calculation with additional stages and modules, the calculation method approximates more closely the real climate impact over the building's life cycle and provides more opportunities to reduce it in a holistic view. Conversely, the calculations of the modules may require considerable costs and time, especially where there is a lack of available and accurate environmental data for related processes and products. The introduction of additional modules in the calculation of the climate impact of buildings must therefore be assessed in relation to these considerations.

This report investigates how to define the scope of the so-far excluded modules, their relative importance to the total climate impact on the product and building level, as well as the time and effort-associated with introducing them in the climate declaration requirement.

How can the scope of the excluded modules be defined?

General rules for modules A4, A5, B1, B2, C1 and C2 are laid down in EN 15978:2012, which is currently under revision. While experiences and insights are currently being made in the industry in how to handle A4 and A5 within the context of the voluntary sustainability class and as closely as possible to the scope defined in the standard, practice is limited regarding handling modules B1 (use) and B2 (maintenance) in building LCAs. This is due to the so far unclear processes they include.

With the ongoing revision of the standard, B1 becomes relevant for materials or products emitting or binding greenhouse gases (GHGs) in the use stage. This applies to refrigerants emitted due to leaks from building systems during use, as well as CO_2 removals due to natural processes such as carbonation of cementitious products and sequestration by vegetation.

B2 (maintenance), in theory and practice, is often difficult to clearly distinguish from B3 (repair) and B4 (replacement), which has led to different interpretations in LCA methods in different countries. Maintenance should be understood as the set of context-related operations performed under normal conditions. B2 also applies to complex product systems

consisting of components, whose service life is shorter than the overall product system. This has consequences for the replacement of glass in windows and facades currently included in B4.

Concerning C1 (deconstruction) and C2 (transport), the challenge they pose is not about defining their scope as they are conceptually similar to A4 and A5, but their inherent uncertainty as they represent far future activities.

Which product categories would be affected, and what is the level of data availability?
B1 is relevant for cement- and lime-based products such as concrete and different types of mortars. B1 values are already provided in most EPDs for concrete products, but typically as one or two values representing different degrees of carbonation. A more detailed distinction between various scenarios based on which surface layers of the concrete are exposed and how, the concrete's compressive strength and the thickness of the construction, and other factors that affect CO_2 absorption, is largely missing. To properly use the already available datasets would necessitate the inclusion of more options for B1 values in concrete and cement datasets. European standards for the calculation of this effect are already established.

B1 also affects building-integrated technology systems that use refrigerants like air conditioners and heat pumps. Although refrigerant impacts are rarely considered in LCAs, the EU F-gas regulation from 2015 has drawn attention to this issue over the past few years. As a result of the regulation, refrigerants with high climate impact are subject to sectoral bans, among other measures, designed to promote the use of new and alternative refrigerants that have a low climate impact (and novel technologies). B1 can constitute a large part of the total impact of an air-conditioning system in a 50-year reference study period (RSP) depending on the refrigerant used and the leak rate. Since the impact per kg is typically known and provided in generic databases for different types of refrigerants, it is possible to calculate, based on a simple formula, the impact of refrigerant leakage in B1 and during decommissioning of the system in C1, if the related leak rates are provided by the system manufacturers or default scenarios are given through regulation.

A final aspect of B1 is the net CO_2 sequestration in vegetated building surfaces like green roofs. Vegetated surfaces sequester CO_2 during their lifetime but also release CO_2 and CH_4 during decomposition, which leads to a relative balance of carbon absorption and release. Parts of the effects of these processes are usually reported under B1, but clear rules have not yet been established leading to varying allocation approaches. In such a case excluding B1 would result in including only one part of this balance in the calculations and hence false conclusions about the environmental benefits of vegetated surfaces.

The potential reallocation of some of the replacements currently being under B4, such as window glass, is one of the most important elements in B2. For further relevant aspects like cleaning agents and oils to maintain floors and other surfaces, there is a low availability of consistent impact data. Generic data and scenarios could be developed from available product specific Environmental Product Declarations (EPDs). Furthermore, the frequency of cleaning and maintenance does not only depend on the type of surface but also the pattern and conditions of use of a building as well as the place of installation of the product within the building; this would necessitate that the relevant data from EPDs are adjusted according to the project-specific maintenance scenario.

Finally, C1 is considered negligible for most products and therefore often not included in EPD according to EN 15804+A1 but however its declaration is mandatory for +A2 data. Ready-mix concrete products are among the few that have relevant C1-associated impacts on the product level, if considered with todays' conditions (diesel-consuming equipment). On the other hand, C2 is available for most products in both generic and product specific EPDs but its impact is negligible.

What is the added impact?

This report examines this question based on the analysis of 10 building cases of different types and qualities. It studies the influence of an extended life cycle scope (A4, A5, B1, B2-3, C1, C2), as well as adjusted B4 data in line with the most recent standardization developments, on the total climate impact. The case buildings come from DGNB-certified projects, external projects and life cycle assessments carried out by BUILD. The sample of buildings consists of two commercial buildings (ER), two apartment buildings (EB), two single-family house buildings (EKR), two office buildings (KB) and two institutional buildings (IN). (**Figure 1**).

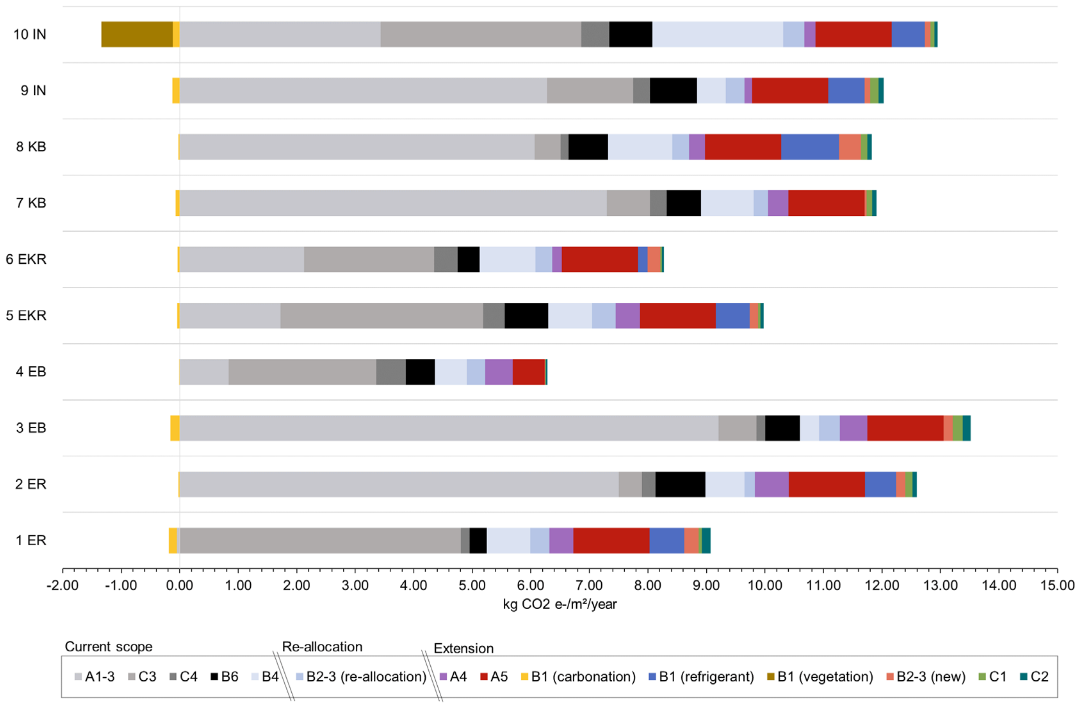


FIGURE 1: Overview of the life cycle impact per building case and module for a 50-year reference study period.

A noteworthy finding from this analysis is that missing modules can increase the overall climate impact result by 2.77 kgCO_2eq/m^2/year in a 50-year reference study period (**Figure 2**, median values). This corresponds to 24% of the whole life cycle impact. Other than module A5 which is taken as a default value (1.30 kgCO_2eq./m^2/year, except for prefabricated case building 4EB where a value of 0.55 kgCO_2eq./m^2/year was applied assuming that no or little waste is generated on site), the second largest contributor to this increase is module B1 due to the impacts of refrigerants; the median value is 0.58 kgCO_2eq/m^2/year, with the highest value reaching close to 1 kgCO_2eq/m^2/year (**Figure 3**). The default value used for A5 is based on real data from 50 construction sites in Denmark collected within the context of REBYG project (BUILD report 2023:14).

The rest of the missing modules affect the overall result to a much lower degree with median values for A4, B2, C1 and C2 accounting for (0.41) (0.47) (0.08) and (0.07) kg CO_2 eq/m^2/year in a 50-year reference study period, respectively. In the case of B2 module, 67% of its associated impact can be attributed to the reallocation of glass replacement and paintwork from B4, rather than newly added impacts. Concerning the uptake of CO_2 during natural carbonation of cement- and lime-based products, this can offset 0.15 kgCO2eq/m^2/year, which constitutes roughly 1% of the median total impact based on the new calculation (11.70 kgCO_2eq./m^2/year). The scenario for carbonation applies the actual degree of exposure of concrete, which in most building cases, walls was obstructed by paint, which reduces the effect.

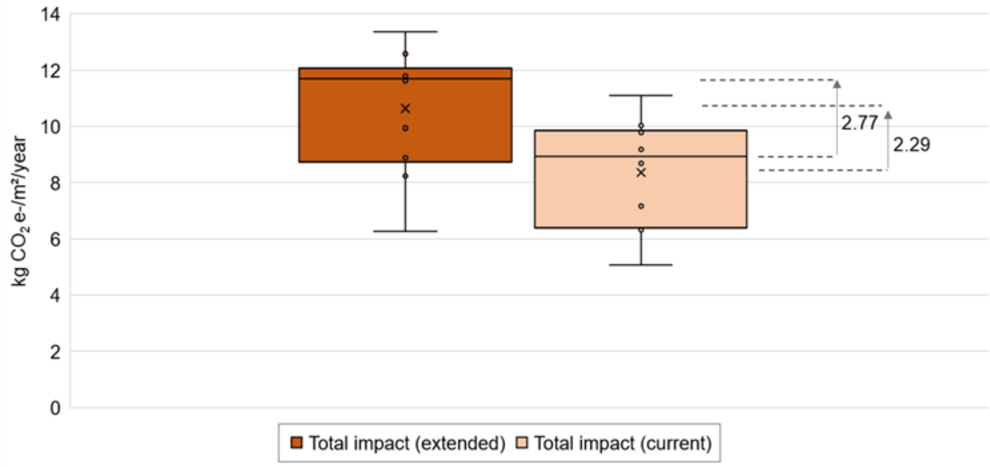


FIGURE 2: Comparison of the range of the new lifecycle impact results that represent an extended scope (A1-3, A4-5, B1, B2, B4, B6, C1-2, C3-4) vs the current scope (A1-3, B4, C3-4) based on 10 building cases of various types. The median climate impact for the former is 11.70 $kgCO_2eq./m^2/year$, while for the latter 8.93 $kgCO_2eq./m^2/year$.

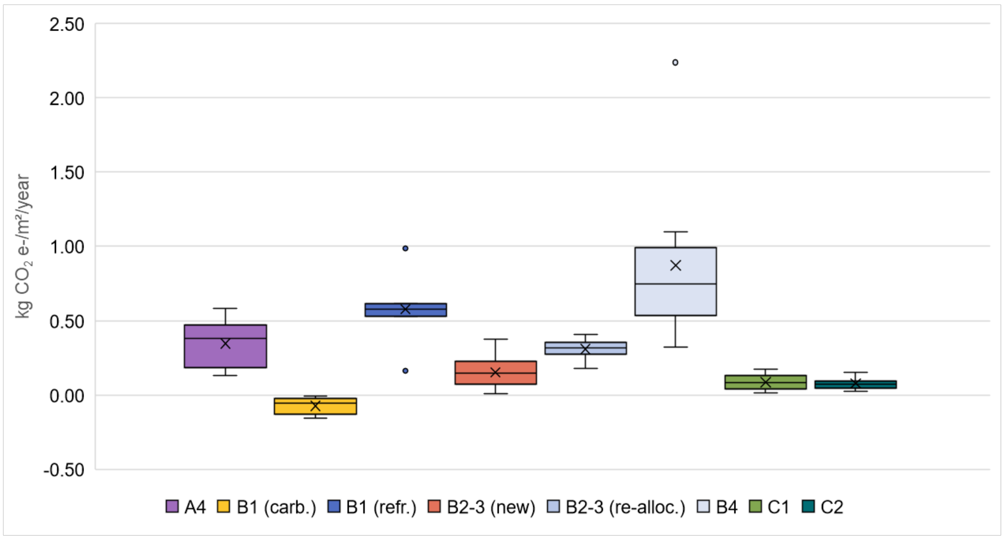


FIGURE 3: Ranges of different missing modules from the current scope (A4, B1, B2, C1, C2) and new results on B4 (recalculation with subtraction of glass replacement of windows and paintwork) based on 10 building cases of various types. Note: Construction site impacts (A5) and the effect of carbon sequestration due to a green roof (B1(vegetation)) are not in the graph as they constitute single values in this study.

Summary of short-term possibilities and implications of extending the current scope

The revision of limit values in 2025 and 2027 also provide the opportunity to revisit the scope of the method itself, as it has a significant impact on the national construction sector's carbon footprint. The following potential improvements should be considered in the short term:

- Include transport (A4) and construction site (A5) climate impact in the short-term future regulatory limits, if needed, initially allowing the use of default emission factors for different activities, such as transport, waste or energy consumption on site, etc. This is necessary owing to the high impact of A5 and the possibility of the industry to have an immediate influence on both. However, it is suggested that a requirement is placed that, especially for the construction site impact, every project documents an accurate result, but with the permission to use fixed default values up to 2027. This will still drive the market to develop solutions that can achieve significant carbon impact reductions on site.

- Include the refrigerant-associated impact either in the short-term future regulatory limits or include its calculation and reduction as an additional requirement. The implications of not considering the refrigerant leakage impact are important. Choosing one type of refrigerant over another has a far more significant climate change mitigation potential than optimizing the rest embodied carbon of HVAC systems. To estimate the refrigerant leakage effects on building's carbon footprint in (B1) and (C1), a simple calculation method can be employed, consisting of a standard annual leakage rate for the use stage, and a standard system replacement and decommissioning leak rate for the end-of-life stage. Data on the total initial charge of the refrigerant in a system can be obtained by manufacturers or generic data can be generated by the method based on specifications for the most typically used heat pump and HVAC products on the Danish market. The inclusion of this aspect will give an additional incentive to designers and engineers to prioritize systems of low-impact refrigerants in their projects with a minimal additional workload for the calculation and documentation.
- Consider conservative ways to include carbonation of cement- and lime-based products as a natural well-documented phenomenon until more diverse data is available. Carbonation provides an opportunity to offset some of building's emissions, however, this effect is small. Moreover, carbonation beyond a certain level is not desirable in reinforced concrete; the changed pH value may have adverse effects on the robustness of the embedded steel bars. Carbonation rates depend on the duration of exposure, concrete type and the exposure conditions including any surface treatments. Therefore, it predominantly applies to exposed concrete elements and mortar. As manufacturers provide such data a direct inclusion would be possible if a carbonation potential can be proved (e.g. uncovered surface).
- Consider including a default value for B2 to cover processes other than glass replacement and paintwork until more usable data becomes available. Although B2 usually has a low relative importance, it can demonstrate the advantages of concepts such as low maintenance houses. The inclusion of B2 may also encourage producers to indicate such values in their EPDs. Unlike carbon footprint, maintenance-intensive products can have a considerable effect on life-cycle costs or other environmental and health-related indicators. In addition, regular cleaning and maintenance help extend the life of the building, thus avoiding unnecessary waste, repair and replacement associated with building deterioration.
- Consider including deconstruction and transport activities (C1 and C2) initially with a default value and ideally per m^2 of building for completeness. C1/C2 covers emissions far into the future, and their uncertainty, combined with their relatively small importance means that it is unreasonable to require the industry to spend time and resources calculating them in detail. Ideally, the future decarbonization of the electricity grid should be considered when generating default values.

RESUMÉ

En bygnings livscyklusvurdering (LCA) består af forskellige faser, som er opdelt i moduler i henhold til den europæiske standard EN15978. Modulerne beskriver påvirkninger af de forskellige processer, der skal indgå i vurderingen.

Som reaktion på klimaændringer er behovet for hurtig handling presserende. Dette har ledt til, at flere lande i Europa har indført eller er i færd med at indføre krav om at udføre LCA og overholde grænseværdier i deres bygningsreglementer. Omfanget af metoden og de inkluderede moduler varierer dog bland landene. Mens Holland og Frankrig dækker et bredere anvendelsesområde og kræver medtager alle moduler, har lande som Sverige en mere snævert afgrænsning, som kun medtager CO2-emissioner der er sket før ibrugtagning (engelsk: upfront carbon), som inkluderer produktion (A1-3) og byggeprocessen (A4-5).

For Danmarks vedkommende er det på grund af begrænsede data ikke alle moduler, der er omfattet af kravet om bygningers klimapåvirkning, som blev indført pr. 1. januar 2023 i bygningsreglementet. I øjeblikket omfatter bygningsreglementets metode Produktfasen (A1-3), Udskiftninger (B4), Energi til bygningsdrift (B6) og Affaldshåndtering (C3-4). Modul D skal deklareres separat.

For at sikre så retvisende beregninger som muligt bør flest mulige moduler medtages i i afgrænsningen af fremtidige grænseværdier og med en så høj detaljeringsgrad som muligt. Ved at udvide klimaberegningen med yderligere faser og moduler tilnærmer beregningsmetoden sig mere præcist den reelle klimapåvirkning i bygningens livscyklus og giver samtidig flere muligheder for at reducere klimapåvirkningen i et helhedssyn. Omvendt kan beregningerne af modulerne imidlertid medføre betydelige omkostninger og tid, især hvor der mangler tilgængelige og nøjagtige miljødata for relaterede processer og produkter. Indførelsen af yderligere moduler i beregningen af bygningers klimapåvirkning skal derfor vurderes under hensyntagen hertil.

Denne rapport undersøger, hvilke processer der bør inkluderes i de hidtil manglende moduler, deres relative betydning for den samlede klimapåvirkning på produkt- og bygningsniveau samt den tid og de omkostninger, der er forbundet med at indføre dem i bygningsreglementets klimakrav.

Hvilke processer bør indgå i de manglende moduler?

Reglerne for LCA for modul A4, A5, B1, B2, C1 og C2 er generelt fastsat i EN 15978:2012, som i øjeblikket er under revision. I forbindelse med delkrav 2 i den frivillige bæredygtighedsklasse har nogle aktører i byggebranchen allerede opnået de første erfaringer med modulerne A4 og A5.. Der er dog kun sparsom praksiserfaring med hensyn til håndtering af modul B1 (brug) og B2 (vedligeholdelse) i bygnings-LCA'er. Årsagen er, at det hidtil har været uklart, hvilke processer de specifikt omfatter.

Med den igangværende revision af standarden bliver B1 relevant for alle materialer eller produkter, der udleder eller optager drivhusgasser i brugsfasen. Dette gælder fx kølemidler, der udledes på grund af lækager fra tekniske bygningsinstallationer under brug, samt CO_2-indlejring gennem naturlige processer såsom karbonering af cementholdige produkter og plantevækst.

B2 (vedligeholdelse) er ofte vanskeligt at skelne fra henholdsvis B3 (reparation) og B4 (udskiftning), hvilket giver mulighed for afvigende fortolkninger i nationale LCA-metoder. Vedligehold bør forstås som kontekstbaserede tiltag, der udføres under normale forhold. B2

finder også anvendelse på komplekse produktsystemer, der består af komponenter, hvis levetid er kortere end det samlede produktsystem. Dette har blandt andet konsekvenser for udskiftningen af glas i vinduer og facader, som i øjeblikket er placeret under B4.

Med hensyn til C1 (dekonstruktion) og C2 (transport) er udfordringen ikke at definere deres inkluderede processer, da de ligner A4 og A5 i deres struktur, men derimod deres iboende usikkerhed, da de repræsenterer aktiviteter langt ude i fremtiden.

Hvilke produktkategorier vil blive påvirket, og hvilke data er tilgængelig?
B1 er relevant for cement- og kalkbaserede produkter som beton og forskellige typer mørtel. B1-værdier findes allerede i de fleste miljøvaredeklarationer (EPD'er) for betonprodukter, men typisk som én eller to værdier, der repræsenterer forskellige grader af karbonering. Der mangler dog en mere detaljeret sondring mellem forskellige scenarier, der påvirker CO_2-optaget og dermed klimapåvirkningen. Det gælder forhold som hvilke overfladelag af betonen der eksponeres og hvordan, betonens trykstyrke og konstruktionens tykkelse. Korrekt anvendelse af de allerede tilgængelige datasæt ville nødvendiggøre medtagelse af flere muligheder for B1-værdier i beton- og cementdatasæt. Der findes allerede relaterede europæiske standarder for beregning af denne effekt.

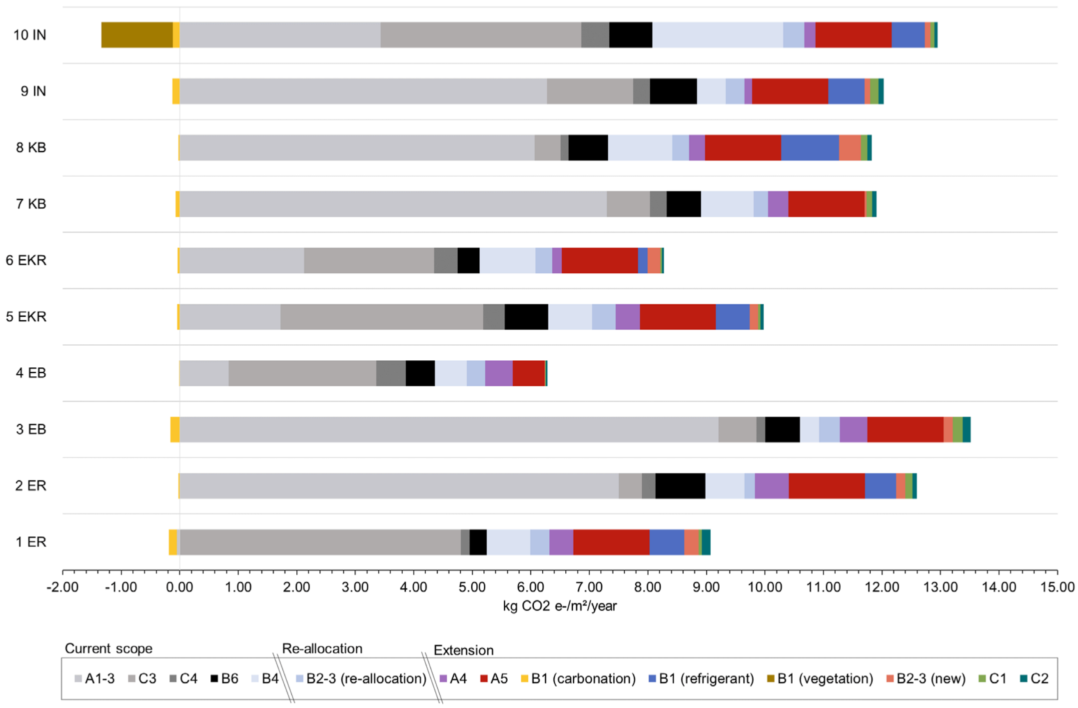
B1 påvirker også tekniske bygningsinstallationer, der bruger kølemidler som fx klimaanlæg og varmepumper. Selvom påvirkninger forbundet med kølemidler sjældent medtages i LCA'er i dag, er opmærksomheden blevet henledt på dette problem i de seneste år på grund af EU's F-gasforordning fra 2015. Som et resultat af reguleringen er kølemidler med høj klimapåvirkning underlagt sektorafhængige forbud, blandt andre foranstaltninger, der har til formål at fremme brugen af nye og alternative kølemidler med lav klimapåvirkning og nye teknologier. B1 kan udgør en stor andel af den samlede påvirkning for et klimaanlæg over en 50-årig levetid afhængigt af det anvendte kølemiddel og lækageraten. Da påvirkningen pr. kg typisk er kendt og givet i generiske databaser for forskellige typer kølemidler, er det muligt, på baggrund af simple formler, at lave en beregning af virkningen af kølemiddellækage i B1 og under nedlukning af systemet i C1, hvis de relaterede lækagerater er opgivet af producenten eller gennem faste scenarier.

Et sidste aspekt af B1-modulet er netto kulstofoptaget i beplantede bygningsoverflader som fx grønne tage. Planter og jord binder CO_2 i løbet af deres levetid, men frigiver også CO_2 og CH_4 under nedbrydning, hvilket fører til en relativ balance mellem optagelse og afgivelse. Dele af virkningerne af disse processer rapporteres normalt under B1, men der er endnu ikke fastlagt klare regler, hvilket fører til forskellige metoder til allokering mellem modulerne. I et sådant tilfælde ville udelukkelse af B1 medføre, at kun en del af denne balance vil blive medtaget i beregningen, som kan resultere i forkerte konklusioner om miljøfordelene ved beplantede overflader.

Det mest relevante emne i modul B2 er den potentielle omfordeling af vinduesruder, som lige nu er allokeret i B4 (udskiftninger). Andre processer i B2 er fx brug af rengøringsmidler og olie til vedligehold af gulve og andre overflader, som i øjeblikket mangler konsistente miljødata. Til forbedring af datagrundlaget kunne der udvikles generiske værdier baseret på produktspecifikke EPDer.. Desuden afhænger hyppigheden af rengøring og vedligeholdelse ikke kun af overfladetypen, men også af bygningens brugsmønster og brugsbetingelser samt placeringen af produktet i bygningen; Dette vil kræve, at de relevante data fra EPD'er justeres i henhold til projektets specifikke vedligeholdelsesscenarie.
Endelig anses C1-modulet for at være ubetydeligt for de fleste produkter. Modulet har derfor ofte ikke været inkluderet i EPDer i henhold til EN15804+A1, men bliver obligatorisk at deklarere efter den nye +A2 standard. Fabriksbeton er blandt de få byggeprodukter, der har ikke-negligerbare C1-relaterede indvirkninger på produktniveauet, hvis de betragtes under nutidens forhold meddieselforbrugende udstyr. På den anden side er C2 tilgængelig for de

fleste produkter i både generiske og produktspecifikke EPD'er, selvom dens påvirkning er altid ubetydende.

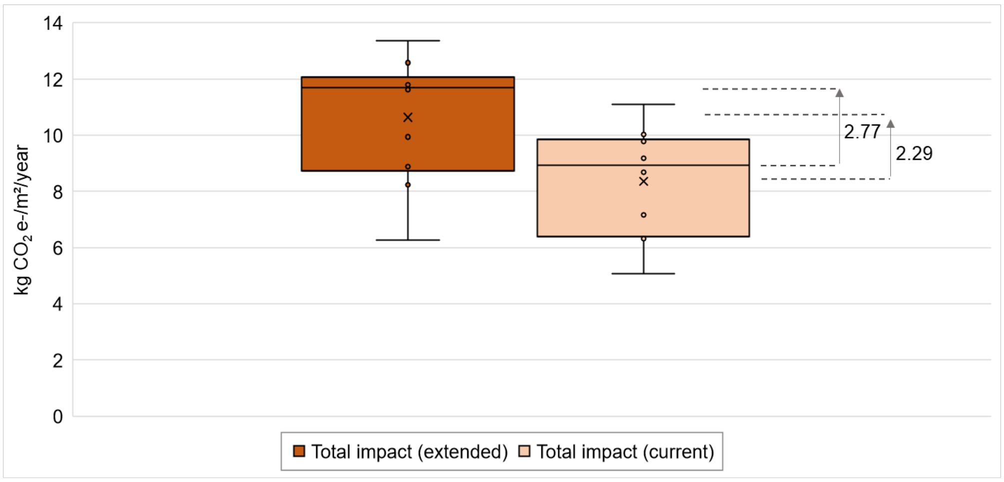
Hvor stor er den øgede klimapåvirkning fra de tilføjede moduler?
Denne rapport undersøger dette spørgsmål baseret på analysen af 10 byggesager af forskellig type og anvendelse. Der undersøges indflydelsen af det udvidede livscyklusinklusive modulerne A4, A5, B1, B2-3, C1 og C2 samt justerede B4-data i overensstemmelse med den reviderede standard på bygningers samlede klimapåvirkning. Casebygningerne kommer fra DGNB-certificerede projekter, eksterne projekter og livscyklusvurderinger udført af BUILD. Stikprøven af bygninger består af to erhvervsbygninger (ER), to etageejendomme (EB), to enfamiliehuse (EKR), to kontorbygninger (KB) og to institutionsbygninger (IN) (**figur 1**).



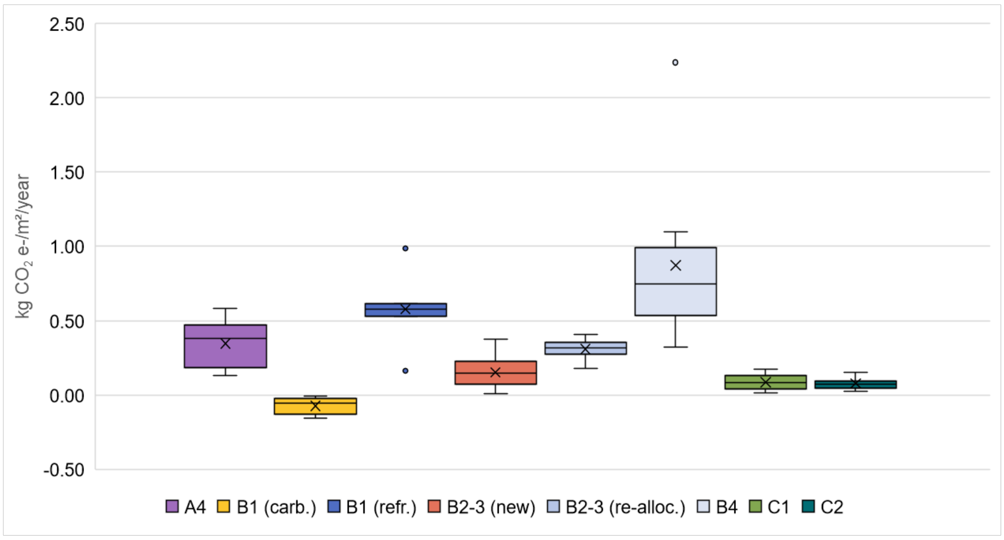
FIGUR 1: Oversigt over klimapåvirkning pr. case og modul over en betragtningsperiode på 50 år.

Et bemærkelsesværdigt resultat af denne analyse er, at manglende modulerkan øge den samlede klimapåvirkning med 2,77 kgCO_2-ækv./m^2/år over en 50-årig referenceperiode (**figur 2**, medianværdier). Dette svarer til 24 % af den samlede udledning for hele livscyklussen. I odul A5 anvendes en standardværdi på 1,30 kgCO_2-ækv./m^2/år, undtagen for den præfabrikerede case-bygning 4EB. Her bruges en specifik værdi svarende til 0,55 kgCO_2-ækv./m^2/år, under antagelse af, at lille eller ingen affald genereres på stedet. Standardværdier for A5 er baseret på en analyse fra 50 byggepladser i Danmark indsamlet inden for rammerne af REBYG-projektet (BUILD rapport 2023:14). Modul B1 den næststørste bidragsyder til den øgede klimapåvirkning, som skyldes brug af kølemidler. Medianværdien er 0,58 kgCO_2-eq./m^2/år med en maksimum værdi tæt på 1 kgCO_2-eq./m^2/år (**figur 3**).

Resten af de manglende moduler påvirker det samlede resultat kun i mindre omfangf, idet medianværdierne for A4, B2, C1 og C2 er henholdsvis (0,41) (0,47) (0,08) og (0,07) kgCO_2-eq./m^2/år. I tilfælde af modul B2 kan 67 % af dets tilknyttede påvirkning tilskrives omfordeling af fx glasudskiftning og maling fra B4 snarere end påvirkninger fra de tilføjede processer. Med hensyn til optagelsen af CO_2 under naturlig karbonering af cement- og kalkbaserede produkter kan dette i kompensere for 0,15 kgCO_2-eq./m^2/år over 50år, hvilket udgør mindre end 1 % af bygningernes samlede klimavirkning, baseret på en komplet livscyklus (11,70 kgCO_2-eq./m^2/år). Scenariet for beregning af karboneringseffekten bruger den eksponeringsgrad af beton, som svarer til casenes faktiske forhold. Da væggene i de fleste byggesager var dækket af maling, er effekten af karbonisering normalt reduceret.



FIGUR 2: Sammenligning af klimapåvirkning med udvidet anvendelsesområde (A1-3, A4-5, B1, B2, B4, B6, C1-2, C3-4) i forhold til det nuværende anvendelsesområde (A1-3, B4, C3-4) baseret på 10 byggesager. Den samlede klimapåvirkning med udvidelsen er 11,70 kgCO_2-ækv./m^2/år i median sammenlignet med 8,93 kgCO_2-ækv./m^2/år uden.



FIGUR 3: Spænd af de manglende modulers bidrag til klimapåvirkning fra det nuværende anvendelsesområde (A4, B1, B2, C1, C2) og nye resultater på B4 (genberegning fratrukket glasudskiftning af vinduer og lakering) baseret på 10 byggesager af forskellige typer. Bemærk: Påvirkninger på byggepladser (A5) og effekten af CO_2-optag fra beplantning fx grønt tag (B1) er ikke med i grafen, da de udgør enkeltværdier i denne undersøgelse.

Sammenfatning af muligheder og konsekvenser ved at implementere nye moduler på den korte bane

Opdateringen af grænseværdier i henholdsvis 2025 og 2027 giver samtidig mulighed for at revidere LCA-metoden, da det har en betydelig relevans for det danske byggesektors CO_2-aftryk. Følgende potentielle forbedringer bør overvejes på kort sigt:

- Medtag transport- (A4) og byggepladsens (A5) klimapåvirkning i de kommende klimakrav og grænsevordier. Om nødvendigt, kan der i første omgang anvendes faste standardværdier for forskellige aktiviteter, såsom transportafstande og affaldstab pr. hovedmaterialetype, standardværdi for energiforbrug på stedet med videre. Dette er nødvendigt på grund af modulets store betydning og industriens mulighed for at få umiddelbar indflydelse på begge. Det foreslås dog, at der stilles krav om, at projekternedokumenterer det faktiske resultat, men med tilladelse til at bruge faste standardværdier til overholdelse af grænseværdien frem til 2027. Dette vil stadig drive markedet til at udvikle gode løsninger til reduktion af CO2-påvirkningen på byggepladsen.

- Medtag klimapåvirkning fra kølemidler, enten i de kommende grænseværdier eller som deklarationskrav. Konsekvenserne ved at udelade påvirkninger fra kølemidler er alvorlige. At vælge en type kølemiddel frem for en anden har et langt større potentiale for at reducere klimapåvirkningen end at optimere resten af de indeholdte CO_2-emissioner i HVAC-systemer. For at estimere lækkage af kølemidler på bygningens CO_2-aftryk i B1 og C1 kan der anvendes en simpel beregningsmetode, der består af en fast årlig lækagerate for brugsfasen og en fast værdi ved udskiftning og affaldsbehandling af systemet.
- Data om den samlede indledende påfyldning af kølemidlet i et system kan fås af producenterne. Alternativ kan generiske data udvikles baseret på specifikationer for de mest typisk anvendte anlæg med kølemidler på det danske marked. Inkluderingen af dette aspekt vil give designere og ingeniører et yderligere incitament til at prioritere systemer med kølemidler med lav klimapåvirkningi deres projekter med en minimal ekstra arbejdsbelastning for beregning og dokumentation.
- Overvej konservative måder til at inkludere karbonering af cement- og kalkbaserede produkter som et naturligt veldokumenteret fænomen, indtil mere specifikke data er tilgængelige. Karbonering giver mulighed for at kompensere for nogle af bygningens emissioner, dog med en beskeden effekt. Desuden er karbonering ud over et vist niveau ikke ønskeligt, da den kan have negative virkninger på armeringsstål. Karboneringsraten afhænger af eksponeringens varighed, betonkvalitet og eksponeringsforholdene, herunder eventuelle overfladebehandlinger. Karbonisering er derfor mest relevant for udsatte betondele og mørtel med åbne og ubehandlede overfladerDa fabrikanterne leverer sådanne data, vil en direkte medtagelse være mulig, hvis mulighed for karbonering kan påvises (fx udækket overflade).
- Overvej at medtage en standardværdi for B2 på kort sigt for at dække andre processer end udskiftning af glas og lakering, indtil mere anvendelige data bliver tilgængelige. Selvom B2 normalt har en lav relativ betydning, kan det demonstrere fordelene ved koncepter som vedligeholdelsesfrie huse. Inkluderingen af B2 kan også give producenterne incitament til at angive sådanne værdier i deres EPD'er. I modsætning til CO_2-aftrykket kan vedligeholdelsesintensive produkter have en betydelig indvirkning på livscyklusomkostningerne eller andre miljø- og sundhedsrelaterede indikatorer. Desuden bidrager regelmæssig rengøring og vedligeholdelse til at forlænge bygningens levetid og dermed undgå unødvendigt spild, reparation og udskiftning.
- Medtag dekonstruktions- og transportaktiviteter (C1 og C2) i første omgang med en standardværdi og ideelt set pr. m^2 bygning for fuldstændighedens skyld. C1/C2 dækker emissioner langt ude i fremtiden, og deres usikkerhed kombineret med den relativ lille betydning betyder, at det er urimeligt at pålægge branchen at bruge tid og ressourcer på at beregne betydningen i detaljer. Ideelt set bør den fremtidige dekarbonisering af elnettet overvejes i forbindelse med genereringen af standardværdier.

1 INTRODUCTION

1.1 Background

Construction contributes by 39% to the global climate impact, of which 11% comes from new materials (World Green Building Council, 2019). While in the past, construction has primarily focused on reducing the operating energy in buildings, in recent years there has been an increasing focus on embodied climate impact associated with building materials and processes.

To respond to this need, Denmark, within the framework of a political agreement on a national strategy for sustainable construction, recently introduced progressive whole-life carbon limits for new buildings in the Building Regulations, starting from 1 January 2023 and the limit value of 12 kgCO_2eq./m^2/year (The Danish Housing and Planning Authority, 2021). This limit applies to new buildings over 1000 m^2, and updated limit values will be introduced in 2025, 2027, and 2029 that will apply to all new buildings regardless of size. Furthermore, the national strategy for sustainable construction simultaneously defines that the updated 2025 limit value must be determined so that 1/3 of new buildings must perform better than currently.

In addition to the requirement in the Building Regulation, a voluntary CO_2 class with a limit value of 8 kgCO_2eq./m^2/year was introduced in order to incentivise the transition to lower carbon footprint of buildings.

As the data collection is growing and experience with working with the limit values is increasing, the review and updating of the limit value for 2025 also considers potential adjustments of the method in the form of introducing calculations of the additional life cycle stages missing from the current scope, among others (**Figure 4**). The inclusion of modules A4 and A5 in the life cycle system boundary has already been tested between 2020-23 as part of the voluntary sustainability class (VSC). There is also an interest in a possible harmonisation with other Nordic regulatory frameworks as well as the European standard for the environmental performance of buildings EN 15978. Revised scope in 2025, 2027 and 2029 can have a significant impact on the national construction sector's carbon footprint.

“LCA” here is used synonymous with climate assessment Global Warming Potential (GWP). This report focuses on new buildings.

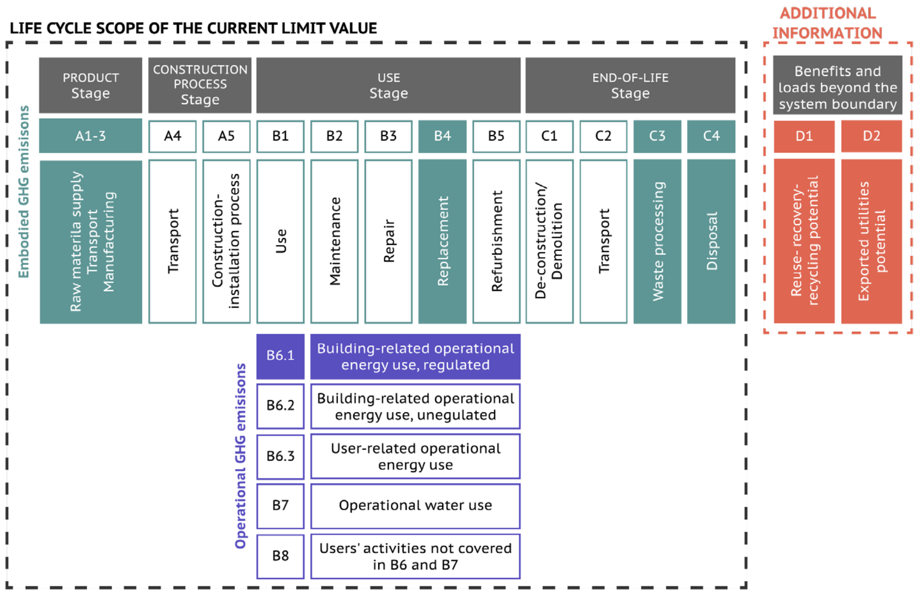


FIGURE 4: Life cycle scope of the current whole-life GHG emission limit for new buildings in the Building Regulations (BR). Module D is reported separately and does not constitute part of the limit value. Note: The Life-cycle model and names of modules are based on Standard EN 15643 (CEN, 2021).

1.2 Purpose

A building's life cycle assessment (LCA) consists of different stages, which are divided into modules according to the European standard EN15978. Modules describe the impacts of the different processes to be included in the assessment. The definition of the scope of an assessment in terms of which modules are included shall be defined based on the LCA purpose.

The purpose of introducing climate regulation for buildings is to mitigate their climate impact. A central question is how much detail is necessary for this purpose as, for example, some modules may be regulated by other instruments.

Due to limited data, not all modules are included in the requirement for the climate impact of buildings, which was introduced as of 1 January 2023 in the Danish Building Regulations.

To ensure as accurate calculations as possible, as many modules as possible should be included in the scope of future limit values, and with as high a level of detail as possible. By expanding the climate calculation with additional stages and modules, the calculation method approximates more closely the real climate impact over the building's life cycle and provides more opportunities to reduce it in a holistic view. Conversely, however, the calculations of the modules may require considerable costs and time, as well as may be subject to uncertainty, especially where there is a lack of available and accurate environmental data for related processes and products. The introduction of additional modules in the calculation of the climate impact of buildings must therefore be assessed in relation to these considerations.

The purpose of this report is to define what the climate, time and economic consequences are of introducing the so-far missing modules in the climate declaration requirement. This input will support decisions for the upcoming adjustments to the requirement for buildings' climate impact, as well as the development of future limit values.

1.3 Reading guide

The report is divided into an introduction (Chapter 1), an analysis of the new modules (i.e. modules out of the current scope) to gain a better understanding of their scope and impact on the total calculation for selected materials and building cases, including an assessment of the workload associated with their calculation (Chapter 2), an overview of how other selected countries with recent or soon-to-be binding climate declarations and limit values are handling the new modules in terms of scope and calculation (Chapter 3), and a summary of the possible advantages and disadvantages of including the new modules in the scope of climate impact calculation and the future limit values from 2025 on as well as a description of the pieces that need to fall into place for that (Chapter 4).

2 ANALYSIS OF MODULES A4, A5, B1, B2, C1, C2

This section analyses modules A4, A5, B1, B2, C1, C2 and looks at the impacts associated with these modules on the total calculation for selected materials and for selected building cases. These are the modules currently excluded from the scope of the Building Regulation (BR). Furthermore, it is also examined how B4 may be affected with the inclusion of B2 in the scope, as well as whether there are missing elements from the current scope of B6 based on the recommendations of the European standards. The analysis involves the following elements presented in individual sub-sections:

- Review of the latest status of EN 15978 standard in terms of what is included in the studied modules, and an assessment of possible scope delimitations thereof if the modules are to be included in the execution of LCA on buildings in Denmark.
- Estimation of the total climate impact of each new module and the effort required for its calculation derived from:
    - analyses on selected material types, where all stages specified in the data sets are included to examine the difference in current scope compared to an extended scope.
    - analyses of 10 building cases of varying type, for examining the influence of including an extended scope (A4, A5, B1, B2, C1, C2), as well as other data in B4, on the total climate impact.
    - estimates of expected additional workload for the parties involved in the data collection, examining: (a) which data are already included in used datasets, (b) which default values can be used, (c) to what extend new scenarios have to be developed.

2.1 Definition of scope in the standard EN 15978

Rules for LCA of modules A4, A5, B1, B2, B3 B4, B6, C1, C2 are generally laid down in EN 15978:2012. This standard is currently under revision. **Table 1-4** provide an overview of how the scope of the new modules is currently defined in EN 15978:2012 and what changes in the form of additions or clarifications are most likely expected to come with the publication of the revised version of this standard (the most recent draft is prEN 15978:2023 as of September 2023 (CEN, 2023)).

TABLE 1 Construction process stage modules A4 (Transport) and A5 (Construction/installation process) - overview of definitions in the standard EN15978 and expected changes in the revised version. Note: MD = Module; VSC = voluntary sustainability class. The expected changes (in terms of additions/clarifications) in the upcoming EN 15978 are based on the draft of September 2023 (CEN, 2023).

MD	National method	DS/EN 15978:2012 (summarised)	EN 15978 (expected changes)
A4	Only in VSC: transport of building materials and soil to the construction site	✓ **transport of materials and products** from the factory gate to the building site, including any transport, intermediate storage and distribution; ✓ **transport of construction equipment** (cranes, scaffolding, etc.) to and from the site; ✓ **all impacts and aspects related to losses due to the transportation** (i.e. production, transport and waste management of the products and materials that are damaged or otherwise lost during transportation).	✓ Clarification that any related **return journeys of vehicles** from the site, intermediate storage and distribution must be included
A5	Only in VSC: ✓ Fuel consumption for machines and vehicles on the construction site ✓ Electricity consumption ✓ Heat consumption ✓ Construction waste ✓ Transport of waste and soil from site ✓ Water use	✓ **ground works and landscaping**; ✓ **storage of products**, including the provision of heating, cooling, humidity, etc.; ✓ **transport on the site**; ✓ **temporary works** necessary for the construction installation process; ✓ **on site production and transformation of a product**; ✓ **provision of heating, cooling, ventilation, humidity control** etc. during the construction process; ✓ **installation of the products into the building including ancillary materials** not counted in the EPD of the products e.g. releasing agents in formworks for concrete, formworks discarded at the end of the project; ✓ **water use** on-site cleaning; ✓ **production, transportation and waste management of products and materials lost** during the construction and installation process. ✓ **waste management processes of other wastes generated on the construction site**	Distinction between different sub-modules: ✓ **A5.1- Pre-construction demolition** ✓ **A5.2- Construction activities** ✓ **A5.3 waste and waste management** ✓ **A5.4- Transport of construction workers** (as additional information)

TABLE 2. Use stage embodied modules B1 (Use), B2-3 (Maintenance and repair), B4 (Replacement) - overview of definitions in the standard EN15978 and expected changes in the revised version. Note: see note in Table 1.

MD	National method	DS/EN 15978:2012	EN 15978 (expected changes)
B1	Not included in BR/ VSC	✓ **Release of substances** from interior or exterior surfaces	✓ **fugitive emissions of refrigerants** from building-integrated technical systems ✓ **removals** (e.g., carbonation, sequestration by vegetation)
B2-3	Not included in BR/ VSC	✓ **production and transportation of the components and ancillary products used for maintenance**; ✓ **all cleaning processes** of the interior and exterior of the building; ✓ **all processes for maintaining the functional and technical performance of the building fabric and building-integrated technical systems, as well as aesthetic qualities** of the building's interior and exterior components (includes painting work on window frames, doors, etc. and also the annual inspection and maintenance of the (oil or gas) boiler, replacement of filters in the heat recovery or air conditioner).	✓ **B2 and B3 are combined in one module** ✓ **In addition to A1-5 of components/products used for maintenance: waste management (C1-4) of the removed parts**, components and ancillary products, and any packaging, ✓ **Cleaning processes are clarified with examples:** cleaning of windows, floors, gutters, etc. ✓ **More examples of processes: recharging of refrigerant** heating, cooling and ventilation systems
B4	Included in both BR and VSC: production and waste processing (A1-3 + C3-4) of any type of new material/ product input during use (also paint, replacement of window or door glass, etc.)	✓ **the production of the replaced component and ancillary products**; (examples are: Replacement of a roof beam, replacement of a partition wall, a complete covering of an existing roofing felt, or a complete renewal including removal of the existing roofing felt, replacement of a heating system or boiler, replacement of a window (frame, glass), etc.) ✓ **the transportation of the replaced component and ancillary products**, including production impacts and aspects of any losses of materials during transportation; ✓ **the replacement process** of the replaced components and ancillary products; ✓ **waste management** of the removed component and of ancillary products;	✓ **Clarifies that B4 is for complete products** e.g. complete window or façade module/component, etc. ✓ **includes packaging in the waste management** ✓ **transport of workers** used to undertake replacement processes to and from the site (only additional information if available).

TABLE 3. Use stage module B6 (Operational energy use) - overview of definitions in the standard EN15978 and expected changes in the revised version. Note: see note in Table 1.

MD	National method	DS/EN 15978:2012	EN 15978 (expected changes)
B6	Uses included in both BR and VSC: heating; domestic hot water supply; air conditioning cooling and humidification/ dehumidification, ventilation; auxiliary energy used for pumps, control and automation; fixed lighting (only for office buildings)	✓ **energy used by building-integrated technical systems during the operation of the building** (as presented in EN 15603. Uses of the building: heating; domestic hot water supply; air conditioning cooling and humidification/ dehumidification, ventilation; lighting; auxiliary energy used for pumps, control and automation). ✓ **energy use of other building-integrated technical systems** (e.g. lifts, escalators, safety and security installation and communication systems) necessary for the technical and functional performance of the building shall be included in B6 and reported and communicated separately.	Distinction between different sub-modules: ✓ **B6.1- regulated energy use of building integrated systems (services)** (shall) ✓ **B6.2- non-regulated energy use of building integrated systems (services)** (should) ✓ **B6.3- other energy use related to building user activities** (e.g., plug-in appliances; computers, washing machines, refrigerators, plug in lighting, etc.) (may)

TABLE 4. End-of-life stage modules C1 (Deconstruction) and C2 (Transport) - overview of definitions in the standard EN15978 and expected changes in the revised version. Note: . Note: see note in Table 1.

MD	National method	DS/EN 15978:2012	EN 15978 (expected changes)
C1	Not included in BR/ VSC	✓ **on-site operations and operations undertaken in temporary works located off-site as necessary for the deconstruction processes** after decommissioning up to and including on-site deconstruction, dismantling and/or demolition.	No significant change expected
C2	Not included in BR/ VSC	✓ **all impacts due to transportation to disposal and/or until the end-of-waste state is reached**. This includes transport to and from possible intermediate storage/processing locations.	No significant change expected

When it comes to the scope of A4 “transport” and A5 “construction and installation” in the current version of the standard, the way currently VSC calculates them includes most of the processes mentioned **(Table 1**). Some missing elements under A4 are the transport of construction equipment to and from the site, as well as transportation losses. However, these are expected to form a tiny share. Furthermore, the consideration of return journeys becomes necessary. VSC allows focusing on five heaviest products and using standard coefficients and transport form. Furthermore, VSC requires projects to meter electricity for seven types of consumption separately in A5. This level of detail was chosen for collecting data for evaluation and identifying energy saving measures and will not be relevant in the final BR implementation.

Regarding use stage module B1 “use” **Table 2** shows that it has been so far unclear as to what specific processes it includes. The release of substances from building surfaces implies a focus on Volatile Organic Compounds (VOCs) which are not relevant for carbon footprint calculations. That is likely the reason why practice is limited in terms of including B1 in building LCAs with a focus on GHG emissions. With the revision of the standard, B1 becomes relevant for any materials or products emitting or binding GHGs in the use stage. This applies to refrigerants emitted due to leaks during the use stage, as well as CO_2 removals. These removals can be due to natural processes such as carbonation of cementitious products and sequestration by vegetation, but in future could also be building-integrated technical solutions available that would allow removals during use. Regarding carbonation of concrete, the inclusion of this effect under B1 has already been part of the related PCR (CEN, 2022).

In the case of B2 “maintenance”, B3 “repair” and B4 “replacement” in theory and practice it is not always easy to clearly determine whether an activity should be considered in any of these modules, which allows for many different interpretations in LCA studies and methods from different countries. As the distinction between B2-4 is not straightforward, the following principles are expected to be more and more adopted in the future: B2-3 as a summarised module encompasses all planned actions related to maintaining the usability or the technical/functional performance of a product or building part/component, such as planned periodic maintenance and cleaning operations. Maintenance is then understood as the set of context-related operations performed under normal conditions (e.g. a product could have different maintenance requirements in different climates). Already in the current version of the standard paintwork is referred to under B2, which differs from the current Danish method where all replacements and renewals are under B4. B2-3 also applies to complex product systems consisting of components, whose service life is shorter than the overall product system. Regarding B4, it encompasses the activities related to replacing an entire product due to damage or at the end of its service life. With that said, the inclusion of B2 will have consequences for B4 due to re-allocation of the impacts of paints and the replacement of glass in windows, doors and glass facades which were so-far considered under the latter module. It is important to note that while B2-3-associated impacts are typically considered unimportant in LCA, this is not the case in Life Cycle Costing (LCC).

In the case of operational emissions, Denmark focuses on the following uses: heating; domestic hot water supply; air conditioning cooling and humidification/ dehumidification, ventilation; auxiliary energy used for pumps, control and automation; fixed lighting (only for non-residential buildings) according to the European standard EN 15603. However, there is a multitude of unregulated energy use within the building not addressed by the regulation. EN 15978 recommends that at least the energy use of other building-integrated technical systems (e.g. lifts, escalators, safety and security installation and communication systems) shall be included in the minimum requirements but as separate information (**Table 3**).

Concerning C1 (deconstruction) and C2 (transport), the challenge they pose is not about defining their scope as they are conceptually similar to A4 and A5, but their inherent uncertainty as they represent far future activities.

2.2 Associated climate impact for selected material and product types

The following material and product types have been identified as relevant for the missing modules from the current scope and/or new considerations under B4 and B6 for the reasons mentioned in **Table 5**. The climate impact of including these new modules on the total impact for the selected material types are analyzed in the following subsections.

TABLE 5: Overview of product types that may be affected by the inclusion of new modules in the life cycle scope of BR 2025 and short explanations. Note: All types of products are associated with A4 and A5 impacts but only few are relevant in terms of importance; in this table A4 and A5 are only discussed for products that are expected to report a notable percentual contribution (e.g. above 5%) to a product's total climate impact.

Type of product (related section)	**Associated new module including short explanation**
Cementitious and lime-based products (2.2.1)	**A4**: Although ready-mix concrete products usually have a short distance from production site to construction site, cementitious products like fiber cement boards may be imported and thus be subject to long distances. **B1**: Natural carbonation occurs, i.e. CO_2 absorption, when cementitious and lime-based surfaces are exposed to air during the use stage. **C1**: At the end of the life, concrete structures will usually be torn down using an excavator mounted with a concrete hammer or concrete shears. Then load the concrete in a container/truck with an excavator. This process consumes a relevant amount of energy.
Heating, ventilation and cooling (HVAC) systems (2.2.2)	**B1**: Air-conditioning systems and heat pumps typically include refrigerants/cooling agents. The same applies to large ventilation systems including a heat pump. **B2**: (a) Regular filter replacement is a common maintenance process for cooling systems and ventilation units to preserve a good indoor air quality. The LCA impacts of newly installed and replaced filters during operation become part of B2. (b) Refrigerant refill when more than 10% of it is lost during the use of a system is a typical maintenance task.
Windows, doors and glass facades (2.2.3)	**B2**: (a) The replacement of its constituent sub-products such as the insulating glass unit (IGU), sealants, fittings, etc. if their service life is shorter than the entire window. (b) The cleaning process of the window (cleaning agent, water consumption, energy use for lifts/cranes, etc.) **B4**: Subject to changes if the glass replacement impacts (as well as replacements of sealants and fittings when included) are allocated to B2 instead of B4 as is the case in other countries and recommended in the product category rules for windows and doors.
Interior and exterior surfaces (2.2.4)	**B2**: (a) paintwork. (b) cleaning and maintenance of flooring and other surfaces. **B4**: subject to changes due to the shift of the paint impacts to B2.
Vegetated surfaces (2.2.5)	**B1**: Vegetated surfaces (e.g. roofs, facades) sequester CO_2 during their lifetime but also release CO_2 and CH_4 during decomposition. Parts of the effects of these processes are usually reported under B1. **B2**: The regular application of fertilisers during use which is typically declared under B2 but sometimes can also be seen under B1.
Roofing felt (2.2.6)	**A5:** Besides the wasted product during installation, the production of fastening materials, and production and combustion of propane for torching are also here included which could be significant. **B4**: Subject to change if the replacement procedure is considered as laying new sheets on top of the existing ones (closer to real practice), and not replacing the existing ones with news (current method).
Elevators (2.2.7)	**B6:** Subject to change due to consideration of energy consumption associated with elevators.

2.2.1 Cementitious and lime-based products

There are many different types of products under the category cementitious and lime-based products, i.e. ready-mix concretes, precast elements, various types of boards, as well as mortars, all with different attributes that influence the relative importance of the new modules to the whole life cycle impact. This is displayed in **Figure 5** using three specific examples. The implications are discussed in the following paragraphs.

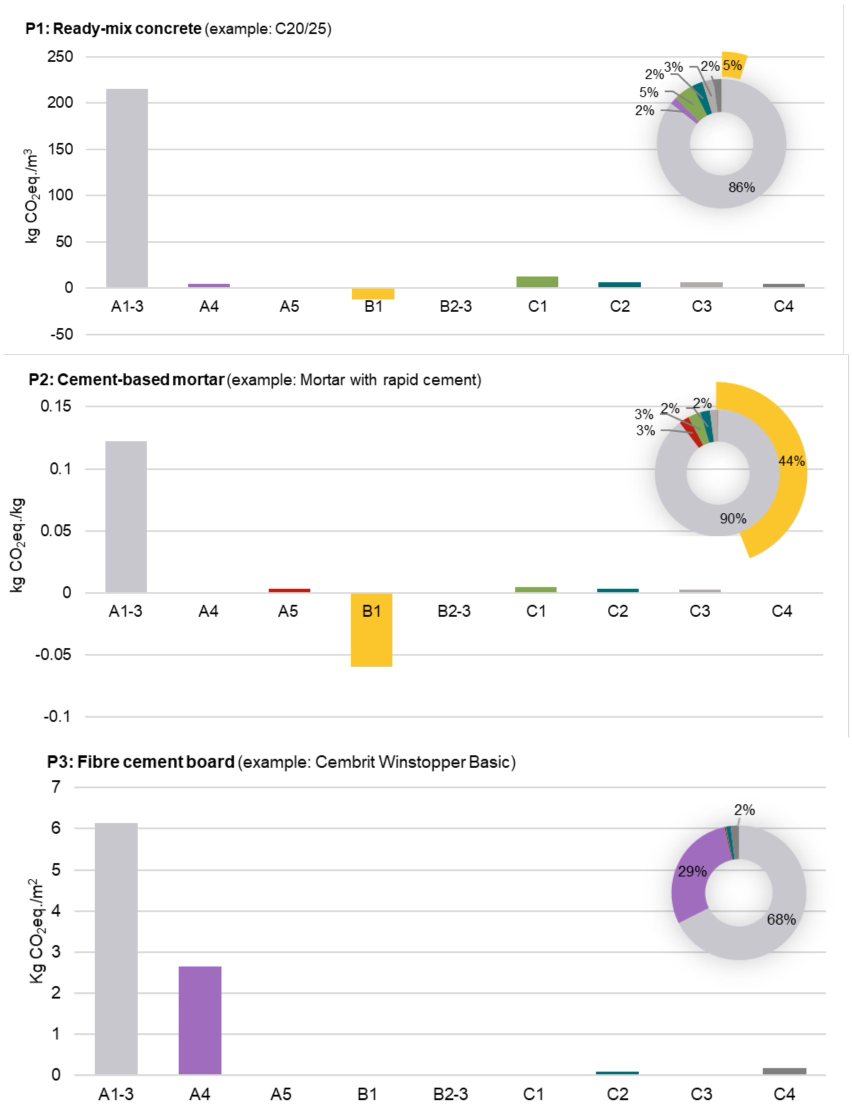


FIGURE 5: Overview of impacts of cementitious and lime-based products, including the new modules where available, based on three examples: P1 is based on the industry EPD for C20/25 ready-mix concrete (MD-20011-DA_rev1) and the B1 values were multiplied by 0.7 to convert them to a 50-year reference study period; P2 and P3 are based on product-specific EPDs (MD-23044-DA and MD-21010-EN, respectively) and were chosen as examples due to their high relative shares of impacts associated with new modules, and not due to their high representativeness of the respective sector. Note 2: The EPD for P3 indicates a zero B1 value.

Transport-associated impacts (A4)

For ready-mix concrete products, the relative contribution of A4-related impacts to the overall product's life cycle impacts appears to be small according to the impact values (kgCO_2eq./declared unit) provided in the Danish industry EPDs (example P1, **Figure 5**), mainly due to the short distance assumed (i.e. 25-75 km). There are no A4 impact values provided in most EPDs for mortars, and therefore not shown here. However, looking at product-specific EPDs, for some cementitious and lime-based products imported from abroad, such as fiber cement boards, A4 can make up nearly 30% of the total impact on the product level due to the higher distance (example P3, **Figure 5**).

Carbonation impacts (B1)

Carbonation is a natural process where the CO_2 released from the limestone ($CaCO_3$) in the production of lime and cement is reabsorbed when reacting with compounds in the concrete and other lime and cement-based products during the use and end-of-life stages.
It may also be considered during production stage module A3 (e.g. induced carbonation, long term storage before delivery). During use, this natural phenomenon can only be prevented by hindering the concrete surface to come into contact with air, e.g. by applying coatings. Calculation of the concrete's carbon dioxide uptake is specified in the product category rules (PCR) for concrete and concrete elements, DS/EN 16757 *Product Category Rules for concrete and concrete elements* (CEN, 2022). Moreover, the report DS/CEN/TR 17310:2019 *Carbonation and CO2 uptake in concrete* (CEN, 2019) describes how CO_2 absorption is considered in an LCA for concrete, as specified in DS/EN 16757, and provides a detailed basis for the calculation model and the various scientific studies it is based on.

Absorption of CO_2 as a result of carbonation is typically included in generic data and EPD of concrete products under module B1. However, the extent of CO_2 uptake depends on the strength of the concrete and the use scenario (exposure condition, service life) as shown in the calculation formula from DS/EN 16757 Annex BB below (**Equation 1**):

$$\text{CO}_2\text{ uptake at a surface} = k * \left(\sqrt{t}/1000\right) * U_{tcc} * C * DOC \quad \textbf{EQUATION 1}$$

Where,

CO_2 uptake is the total uptake in kg CO_2/m^2 concrete surface during t years;
k is the rate of carbonation for the surface in *mm/√(t)* (k-factor);
U_{tcc} is the maximum theoretical uptake in kg CO_2/kg cement;
C is cement content in kg_{cement}/m^3 of concrete.
DOC is the degree of carbonation for the surface in %;
t is the number of years.

Table 6 provides the k-factors for calculation of depth of carbonation for different concrete strength classes and exposure conditions in buildings as well as the degree of carbonation for different exposure conditions in the case of Portland cement (CEM I). It becomes clear that concretes with a lower compressive strength increase the natural carbonation rate, and hence the CO_2 uptake, while coatings like paint and wallpaper decrease the carbonation rate.

TABLE 6. k-factors [mm/year$^{0.5}$] for calculation of depth of carbonation for different concrete strength classes (cylinder) and exposure conditions, as well as degree of carbonation for different exposure conditions, in the case of buildings according to DS/EN 16757 (other values are provided for civil engineering works). These values are derived from (Lagerblad, 2005).

Concrete strength	***≤ 15 MPa***	***15-20 MPa***	***25-35 MPa***	***≥ 35 MPa***	***Degree of carbonation (DOC)***
Parameters	**Value of k-factor in mm/year$^{0.5}$**				**%**
Outdoor					
Exposed to rain	5.5	2.7	1.6	1.1	85
Sheltered from rain	11	6.6	4.4	2.7	75
Indoor in dry climate[a]					
With cover[b]	11.6	6.9	4.6	2.7	40
Without	16.5	9.9	6.6	3.8	40
In ground[c]	N/A	1.1	0.8	0.5	85

[a]Indoor in dry climate means that the RH is normally between 45 and 65%

[b]Paint or wallpaper (under tiles, parquet and laminate k is considered to be 0).

[c]Under groundwater level k = 0.2

For the sake of simplicity, the present study does not calculate B1 values for different types of concrete applications assuming various scenarios, but looks at the values already provided in generic databases and EPDs to gain insights about the importance of the carbonation effect on product level basis. It is assumed that designers and LCA practitioners will not perform the entire calculation themselves, but use and adapt the values already in place by manufacturers.

Currently, the industry EPDs provided by the Danish concrete industry include two B1 values for ready-mix concrete, representing a high degree of carbonation (assumption: use of concrete as inner wall, thickness 200 mm) and a low degree of carbonation (assumption: use of concrete as foundation, thickness 500 mm, or floors and ceilings), and one B1 value for the rest of concrete products (assuming a certain thickness each time). Sometimes EPDs from other countries include multiple scenarios leading to a varied selection of B1 values depending on the construction geometry, exposure scenario and lifetime within which the element fulfills its function, i.e. 50 or 100 years (e.g. Swedish example: NEPD-2707-1408-SE).

Up to recently B1 values for cement-based mortars have been rarely provided in generic databases and EPDs. For example, B1 values for cement- and lime-based mortars are not yet available in ÖKOBAUDAT generic data but they have started being included in the most recent Danish product specific EPDs. Cement-based mortar is used for rendering, plastering, masonry, maintenance and repairing damaged concrete among other applications. Mortar is normally of lower comprehensive strength and higher porosity than structural concrete, which leads to faster carbonation rate and higher CO_2 uptake – thus higher relative B1 values (example P2, **Figure 5**). In particular, whereas the potential carbonation-associated offset of A1-3 impacts for concrete products ranges within 3-6%, for cement-based mortars, B1 could potentially offset more than 40% of A1-3 climate impact if not coated with another material (**Table 7**).

As most concrete manufacturers use DS/EN 16757:2017 to estimate B1, the reference service life (RSL) of concrete assumed in EPDs is 100 years which is in line with the recommendation in Annex AA of the standard. As earlier mentioned, in some Swedish EPDs a value for 50 years' service life is provided in addition. If not the case, to adjust B1 impacts to 50-year RSL the factor of $\sqrt{50}/_{10}$ = 0.7 can be used as an approximation according to DS/CEN/TR 17310:2019. On this basis, to convert from a 60-year RSL assumed in the recently published EPDs of mortars to a 50-year RSL the B1 values need to be multiplied by a factor 0.93.

TABLE 7: Examples of B1 GWP values provided in EPDs for cementitious products (both industry and product-specific). Note 1: Carbonation rate increases with decreasing strength and thickness. Note 2: the EPDs provide the values for 100 years. The conversion to 50 years is realized by multiplying by the factor 0.7. The converted values are provided in parentheses. The last column represents the share of A1-3 that can be offset by B1 for a 50-year reference study period.

Type of product	***Code***	***Unit***	***100 years (kgCO₂eq./unit) (50 years conversion)***		***B1 share relative to A1-3 (50-years)***
			High carbonation	**Low carbonation**	
C20/25	MD-20011-DA_rev1	m^3	-16.9 (-11.83)	-2.29 (-1.60)	5.5%
C30/37	MD-20012-DA_rev1	m^3	-15.4 (-10.78)	-2.27 (-1.59)	3.8%
C35/45		m^3	-14.1 (-9.87)	-2.46 (-1.72)	3.3%
Precast concrete wall elements	MD-20015-DA_rev1	m^2	-2.41 (-1.69)		3.2%
Precast concrete sandwich elements	MD-20019-DA_rev2	m^2	-4.02 (-2.81)		3.1%
Rendering mortar – normal/finishing render	EPD-IWM-STO-20210128-IBG1-DE	kg	-0.108 (-0.075)		36%
Rendering mortar – normal/finishing render with special properties	EPD-IWM-STO-20210129-IBG1-DE	kg	-0.162 (-0.113)		30%
Rendering mortar – Reinforcement Fibre Plaster	EPD-IWM-STO-20210130-IBG1-DE	kg	-0.147 (-0.103)		24%
Type of product	**Code**	**Unit**	***60 years (kgCO₂eq./unit) (50 years conversion)***		***B1 share relative to A1-3***
Functional mortar VKM 2,5, Rapid cement	md-23044-da	ton	-59.8 (-55.6)		45.6%
Lime mortar 7,7%	MD-23050-DA	ton	-38.9 (-36.2)		46%

To compensate for a potential lack of B1 data or in the interest of simplification, DS/EN/TR 17310:2019 provides a typical average CO_2 uptake of 25 kg CO_2/m^3 of concrete to be applied as a rough single value estimate for concrete in house building structures for 100 years of service life. This typical value is less conservative than the values presented in **Table 7** for the various types of ready-mix concrete and may overestimate the beneficial contribution of carbonation.

Regarding the CO_2 uptake of construction and demolition aggregates, it has been reported that the carbonation rate of demolished concrete is faster than during service life, since after demolition, the exposed surface drastically increases. Concrete after demolition can increase CO_2 uptake by up to 50% in comparison with the structures in service (Maia Pederneiras, Brazão Farinha, & Veiga, 2022). Influencing factors such as particle size, cement content and relative humidity affect the carbonation. Thinner recycled aggregates carbonate faster than the others. The time that the recycled aggregate has been stockpiling before being used as a ground filling material also increases the carbonation percentage (Piccardo & Gustavsson, 2021); the more time crushed concrete is in contact with the air, the more fully carbonated the particle will be. However, EN 16757 standard does not specify the time of carbonation to be assumed at the End-of-life (EoL), which is what defines the level of overall importance of this effect.

Demolition and deconstruction-associated impacts (C1)

In general, C1 module is considered negligible for most products and therefore often not included in an EPD. Ready-mix concrete products are among the few that have C1 values in place. At the end of life, concrete structures usually are torn down using different types of equipment. This is an energy consuming process that makes C1 impacts relevant, considering todays' conditions (diesel-consuming equipment). This is seen in **Figure 5** where C1 accounts for 5% to the life cycle impacts of ready-mix concrete placing it after A1-3 in terms of importance.

2.2.2 Heating, ventilation and air conditioning (HVAC) systems

Leakage of refrigerants (B1, B2, C1)

Building-integrated technology systems using refrigerants may lose a percentage of them during operation through leaks, and during deconstruction when they need replacement or at the building's end-of-life. Causes may be weakened joints over time due to continuous pressure in the system or damaged joints due to poor frost protection, repeated vibrations, and corrosion of the copper pipework over time, amongst others.

Although impacts associated with refrigerants are rarely considered in LCA, attention has been drawn to this issue over the last years due to the EU F-gas regulation applied from January 1, 2015[1]. The regulation aims to phase-down Hydrofluorocarbons (HFCs) – which

[1] Source: https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-legislation-control-f-gases_en

are predominantly used as refrigerants – by 2030 by means of a quota system that restricts the availability of HFCs in the European marketplace as well as sectorial bans on high GWP refrigerants. This intends to encourage applications of new and alternative refrigerants with low GWP and novel technologies. Within the context of this phase out, the use of refrigerants with GWP larger than 750 kgCO_2eq/kg will be prohibited for single split air conditioning systems and heat pumps with less than 3 kg of refrigerant charge. Against this background, it is now recommended to consider the annual leaked refrigerants in B1 and the disposal-related leakage in C1 even for the most basic assessments. This is seen in the recent calculation methodology for embodied carbon of Mechanical Electrical and Plumbing (MEP) systems by the Chartered Institution of Building Services Engineers in the UK (CIBSE, 2021) and it is expected to be more explicitly recommended in the upcoming EN15978 standard.

As shown in **Equation 2**, to calculate the climate impact of leaked refrigerants under B1, assumptions or data on the annual leakage rate in addition to the mass of the refrigerant are required. Accordingly, to calculate the impact under C1, assumptions or data on the recovery rate at EoL are needed.

$$\mathrm{B1_{refr.}} = I_{refr.} * m * L * SL$$ **EQUATION 2**

Where,
$I_{refr.}$ is the impact of refrigerant in kgCO_2eq./kg
m is the total mass of the refrigerant in the system in kg;
L is the annual leak of refrigerant in %;
SL is the service life of the system.

This formula can be used in case B1 and C1 data is not provided as part of the LCA of heat pumps and other systems in generic datasets or EPDs or when the assumptions provided in the data do not match the project conditions. Non-availability of such data currently is the most usual case. For example, when it comes to generic data, only the French database INIES provides default values per unit of e.g. heat pump for B1, which are considerable high, in some cases make up 60% of the total impact and are much higher than A1-3 impacts (see INIES dataset on air-to-air heat pump for commercial buildings of 16kW, with 3.28 kg R410A and 2% annual leak rate).

While ÖKOBAUDAT does not provide B1 values for the affected systems themselves, it includes data on lifecycle impact per kg of different types of refrigerants as shown in **Table 8**. It also refers to a report by the Federal Ministry of the Environment (Huckestein, 2021) which provides the typical values for the required mass m of the refrigerant in kg per kW nominal cooling capacity as well as leakage rates and disposal losses per system type to assist in the calculation as per **Equation 2**.

Important differences in GWP from a refrigerant to another can be observed (R410A and R32 for instance). For the same colling capacity, refrigerant charges vary per type of system and refrigerant. Furthermore, depending on the type of product and the care taken during its installation and maintenance, representative annual leakage rates are in the order of 1-10%, while for the EoL the best scenarios assume 100% recovery and the more pessimistic ones assume 85% recovery for split systems, i.e. systems consisting of indoor and outdoor units (Hamot, Dugdale, & Boennec, 2020). The general leakage scenarios proposed by CIBSE and by Germany can be found in a report prepared within the context of the IEA EBC Annex 72 project (Lützkendorf, et al., 2023).

TABLE 8: Impact in kgCO_2eq. per kg of refrigerant provided in ÖKOBAUDAT version 2023. Note: it includes a conservative factor.

	kgCO2eq./kg of refrigerant			
Refrigerant type (kg)	**A1-3**	**B1**	**C4**	**D**
Ammonia (R717)	5.259	0	-	-4.355
Chlorodifluoromethane (R22)	8.36	2321	-	1.603
Difluoromethane (R32)	5.259	898.7	-	-4.355
Refrigerant R404a	11.45	5006	-	-9.483
Refrigerant R407c	9.763	2108	-	-8.083
Refrigerant R410a	10.51	2479	-	-8.694
Carbon dioxide (R744)	1.096	1.1	-	-0.9073
Lithium bromide	11.49	-	12.67	-
Propane (R290)	0.6554	0	-	-0.5429
Tetrafluoroethane (R134a)	8.078	1705	-	-6.693
Tetrafluoropropene (R1234ze)	6.166	1.1	-	-5.106

For example, considering an air conditioning system of 100 kW and a business-as-usual scenario of 5% leakage rate and R134a refrigerant, B1 can constitute 90% of the total impact of the system in a 50-year service life (**Figure 6**). With a more environmentally friendly choice currently widely available[2] and better maintenance scenario (lower leakage rate) the B1 impact can be reduced by nearly 70%. This reflects the importance of choosing the right scenario as well as the great potential of reductions on a product level basis. The example of the geothermal pump in **Figure 6** shows a relative contribution of B1 of 77% which is close to the relative share that can be derived from INIES data. However, the absolute climate contribution is extreme when the R410A refrigerant is assumed. This also results in a much higher reduction potential of more than 240%.

[2] there is a shift to R-32 by many manufacturers of HVAC systems like Daikin and Carrier

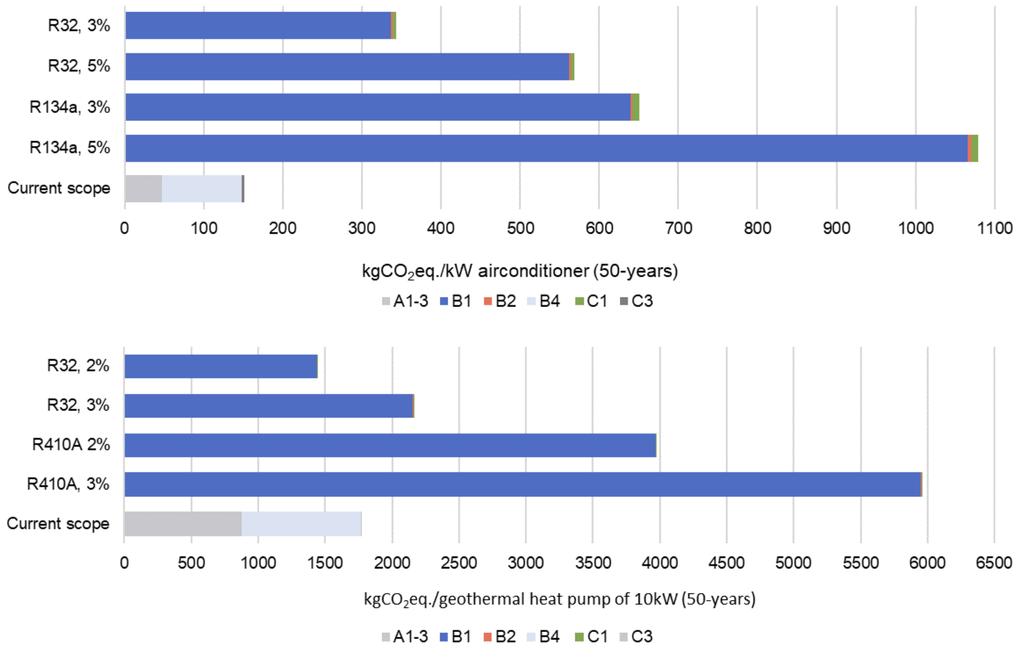


FIGURE 6: Impact of B1 due to refrigerants based on different assumptions (type of refrigerant and leakage rate) using two examples: an air conditioning system and a geothermal pump. Note 1: For the air-conditioning, 0.25 kg of refrigerant charge per kW of capacity (used in IPCC report) and 2 replacements in 50-year SL. The refrigerant charge for heat pump was taken as 1.6kg based on most common charges for this capacity and one replacement was assumed. Note 2: B2 represents the refill of refrigerant when 10% of it is lost, while C1 represents the loss at EoL which is taken as 2% for every system and scenario.

It is important to note that refrigerants also affect module B2 as for a system to operate properly a refrigerant refill ('top up') typically is required when more that 10% is lost. This has been considered in **Figure 6** but is invisible as it has a very small effect. Moreover, the loss at EoL has been considered based on an optimistic scenario (98% recovery rate) as it is assumed that recovery processes will be improved in future. In general, for the EoL the best scenarios assume 100% recovery and the more pessimistic ones assume 85% recovery for split systems (Hamot, Dugdale, & Boennec, 2020).

Filter replacements (B2)

Another main contributor to the total GHG emissions of some HVAC systems like air conditioning and ventilation systems is the filters due to their required replacement minimum once every year. This is essential to ensure that health and comfort requirements for dust and other particles are fulfilled as well as guarantee the performance and service life of all the other components in the system.

The effect of filter replacement is not typically accounted for in generic databases and EPDs. When included, filter replacement is often seen under B4 module on a product level basis. One example is shown in **Figure 7** where the annual filter replacement for a unit with a 25-year service life makes up nearly 15% of the total life cycle impact. Similar conclusions about the importance of filter replacement are also found in literature (Kiamili, Hollberg, & Habert, 2020).

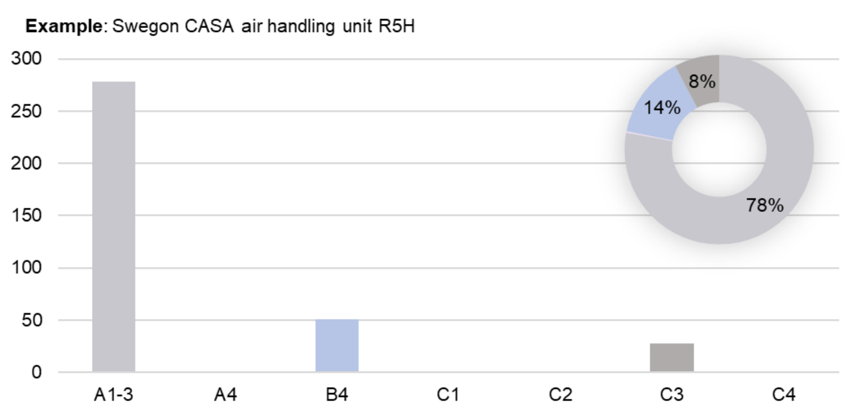


FIGURE 7: Per-module climate impact of an air-handling unit in $kgCO_2eq$./unit (Source EPD: S-P-05388)

2.2.3 Windows, doors and glass facades

There are two aspects associated with windows, glass facades and glass doors that may affect module B2: small replacements of constituent parts of the window with a service life shorter than the frame and the cleaning process.

Glass replacement (B2)

A window is a multi-layered assembly of products where each individual constituent part may have a different service life. In the Danish building regulation, the service life of glass is 25 years, while for the window frame is 50 years. This leads to one replacement just for the glass within a 50-year service life. Despite this difference in service lives of the different window sub-products, the Danish LCA method has always considered any type of replacement in B4.

However, the sector PCR for windows and door sets DS/EN 17213:2020 states that the boundary for maintenance includes *"…Replacement or repair of worn or degraded parts shall be considered for components with a known RSL shorter than the service life of the window (e.g. seals, building hardware and IGU). Any replacement of the complete window or doorset after the RSL of separate components (e.g. seals, hardware, IGU) shall be considered under B4*.". Furthermore, the service life of insulating glass unit should not be more than 30 years. This naturally leads to EPDs for windows and doors that consider the replacement of glass in B2. The same applies to other parts of the window like sealant strips and fittings.

Although the idustry EPD for windows in Denmark does not yet include B2, there are first examples of Danish window producers following this approach and leading to high B2 values, as well as examples from Norway (**Figure 8**). The effect of adopting the approach proposed by DS/EN 17213:2020 and EN 15978 is a reallocation of parts of current B4 impacts to B2 module.

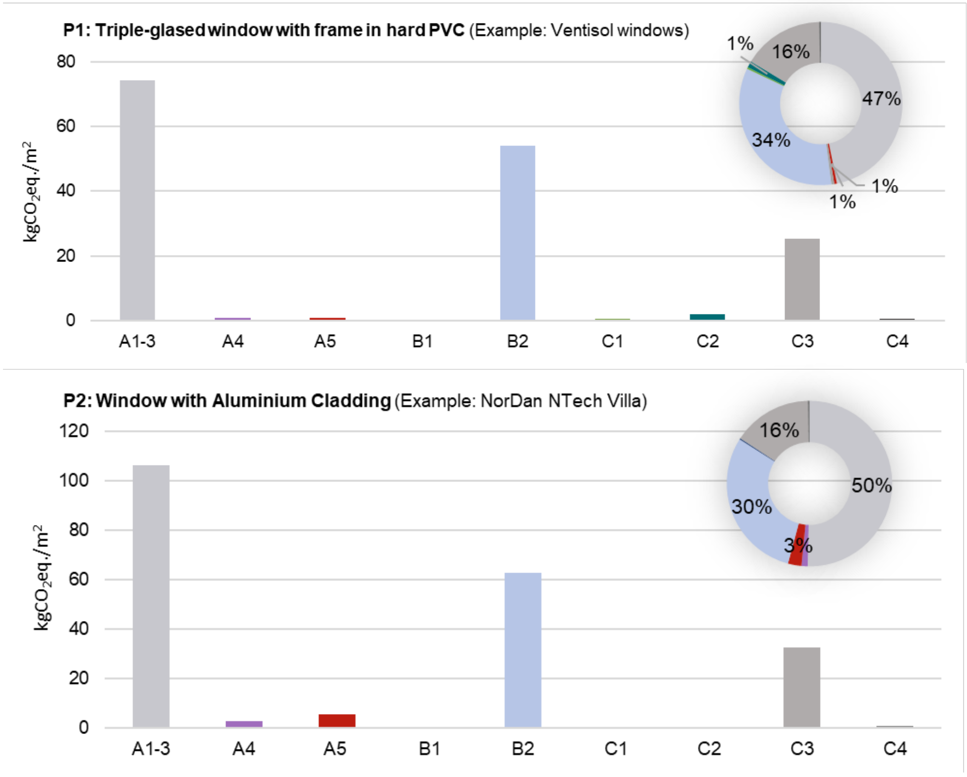


FIGURE 8: Per-module climate impacts of windows in $kgCO_2eq./m^2$ on the basis of a Danish example (source EPD: MD-22126-DA) and a Norwegian example (source EPD: NEPD-4000-3040-EN). Note 1: B2 impacts can be more than 30% of the total life cycle impact of a window. Note 2: The B2 scenarios included in the Danish example are replacement of glass, sealing strips, fittings and hinges as well as cleaning; the scenario in the Norwegian example includes replacement of glass, painting and cleaning.

If the glass and the frame of the window had the same service life as is the case in France where the entire window is considered with a service life of 30 years, B2 values would not include any replacements but only the cleaning-related impacts.

Cleaning of glass surfaces (B2)

Cleaning of windows and doors is mostly influenced by the life cycle impact of the cleaning agent. In many cases this is a manual process with no energy consumption unless lifts for exterior cleaning are used, e.g. in the case of windows opening outwards or high-rise buildings. Furthermore, the GHG emissions associated with the water consumption often are negligible. The assumptions about the frequency of cleaning and the quantity of the cleaning agent differs from country to country. By looking at the INIES default values for windows in which only cleaning was reported in B2, this does not account for more than 0.5% of a window's total impact. It is important to note that also repainting of frames often constitutes part of B2 impact of windows, which can then increase the B2 contribution to 2% (if the glass replacement is excluded).

2.2.4 Interior and exterior surfaces of the building

Typical scenarios involve the definition of a schedule (frequency) and quantities of consumables: i.e. detergent and water used for cleaning, electricity used for non-manual cleaning, lacquer or oil used for wooden surfaces. For some products, maintenance scenarios also involve the replacement of small products such as sealing strips, hinges, etc. for which the definition of replacement cycles and quantities is necessary. In respect to maintenance of surfaces other than glass, according to EN 15978, paintwork is a typical maintenance action that must be included in B2. Other than windows, different types of floor surfaces may include B2 values, with a relative important share being observed for wooden floor for which maintenance involves the use of cleaning and oiling agents (**Figure 9**).

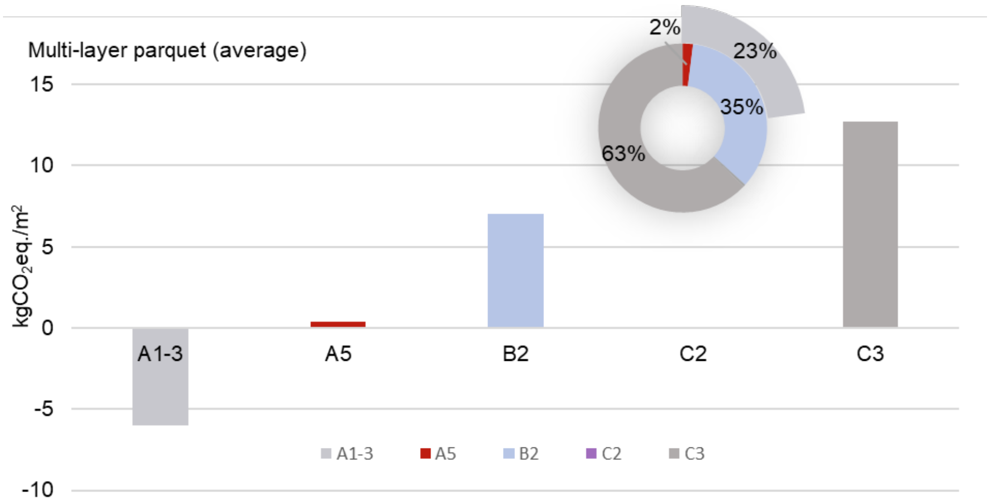


FIGURE 9: Climate impact per module for multilayer-parquet (Source: ÖKOBAUDAT version 2023, average dataset from VdP - Verband der Deutschen Parkettindustrie e.V.).

2.2.5 Vegetated surfaces

Net carbon sequestration

Vegetated surfaces (e.g. roofs, facades) sequester CO_2 during their lifetime. In green roofs, the potential for carbon sequestration is reported to vary from 0.3 $kgCO_2/m^2$/year to 7.1 $kgCO_2/m^2$/year, depending on conditions and variables (Kuittinen, Zernicke, Slabik, & Hafner, 2023). Nevertheless, most of this sequestered CO_2 will stay stored for only a short time. In most studies with green roofs/facades, measurements are based on short-time observations. After the green roof's vegetation has reached a grown stage, it is very likely that the direct amount of carbon taken in by photosynthesis will just balance out the amount of carbon emitted by the natural decay/decomposition of plant material.

No standardized method exists to allocate absorption/decay effects of vegetated surfaces as well as no PCR is available – only few product-specific EPDs following different approaches. The effects of these processes are usually reported under B1 or B2. In theory, plants and soil, together with trees, could help with carbon footprint reductions but mainstreaming their use requires better data and harmonised methods. Based on the existing EPDs on vegetated roofs, three different approaches (among others) are observed as shown in **Figure 10**.

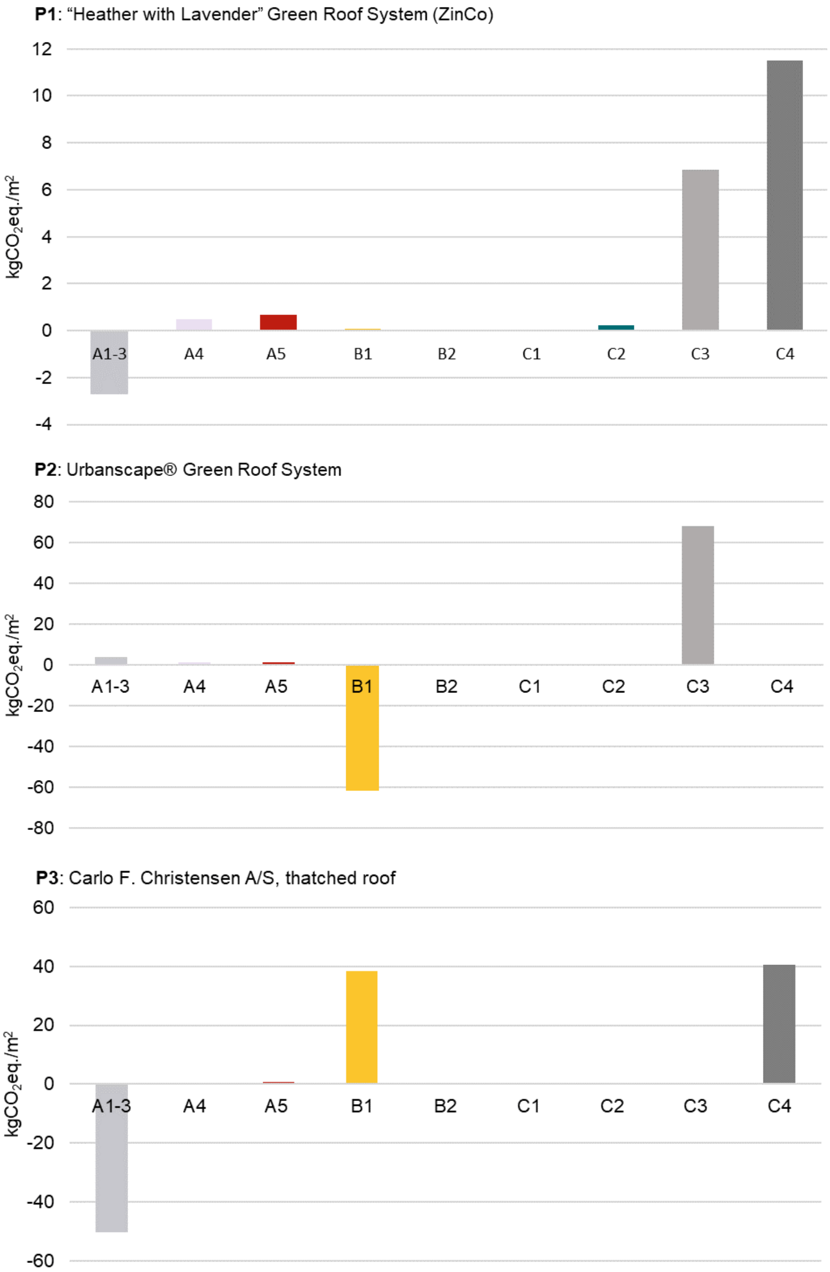


FIGURE 10: Climate impact per module for different vegetated roof products (EPD sources: EPD-ZIC-20200082-CCA1-EN, S-P-05961, MD-17001-EN). Note: For some products, carbon sequestration due to vegetation is allocated to A1-3 (e.g. P1 and P3), while for others it is shown as part of B1 (e.g. P2). The decomposition effect is reported in C4 (P1), C3 (P2), or is shared between B1 and C4 (P3).

According to the standards the -1/+1 rule applies in EPDs of biogenic materials, whereby the biogenic carbon goes to 0 over the product's lifetime. **Figure 10** visualises the impacts per kg $CO_{2eq.}$/m^2 of green roof for the three approaches. What it can be observed is that exclusion of B1 when it invloves either sequestation of decomposition creates a problem: e.g. P1 product ends up having impacts of nearly 70 kgCO_2eq./m^2 which is likely higher than the impacts of the entire roof construction without the greening related layers.

Opposite effects are observed in P3 product that represents a thatched roof, where a natural composting occurs during its lifetime and biogenic carbon is deceased in B1. Excluding B1 would lead to a negative total impact of -8.4 kgCO_2eq./m^2.

Since B1 is not included in the LCA of buildings, there may be products which have an unbalanced carbon absorption across modules A1-A3 and C3-C4. The effects of this problem may be seen in the industry EPD for Danish straw for thatched roofs and facades (Stråtagets Kontor ApS), where the B modules are not declared, which is possible, since EN 15804+A2 mandates to only declare A1-A3, C1-C4 and D. This leads to the product having a negative contribution to GWP (total) of -75 kg CO_2eq./m^2, with only 50% of the CO_2 absorbed considered to be released at EoL (C3).

Fertilisers

Vegetated surfaces involve several other products necessary for their maintenance such as fertilisers. B2 for green roofs typically includes the life cycle impacts of the fertilisers. However, sometimes these impacts can also be seen under B1. Based on the few EPDs available for green roofs as shown in **Figure 10**, the share of B2 is invisible as is no more than 4% of the total impact (based on P2).

2.2.6 Roofing

The way B4 module is currently calculated is by adding the production and installation-related impacts of the replacement product or component to the EoL impacts of the replaced product or component. This equals A1-3, C3-4 impacts of the product under future replacement during use stage. This is a simplified form that does not reflect the usual practice for every type of product. Sometimes products are renewed and not replaced. This is the case for plastic, rubber and reinforced bitumen waterproofing sheets where the replacement procedure will normally be to lay new sheets on top of the existing ones (see: EN 13956, EN 13707, EN 544). The effect of a different consideration of B4 that better reflects the practice is shown in **Figure 11** on the basis of new generic data developed for bitumen sheets (top layer and bottom layer) in BUILD report 2023:15 (Kragh & Birgisdôttir, 2023). A decrease of approximately 88% in B4 impact is observed. This is because only the top layer is added two times during a 50-year service life and no removal of any layer is happening in B4. On the other hand, an increase of more than 125% occurs for C3 as all the layers (3 top + 1 bottom) are removed and disposed at the end-of-life of the entire building.

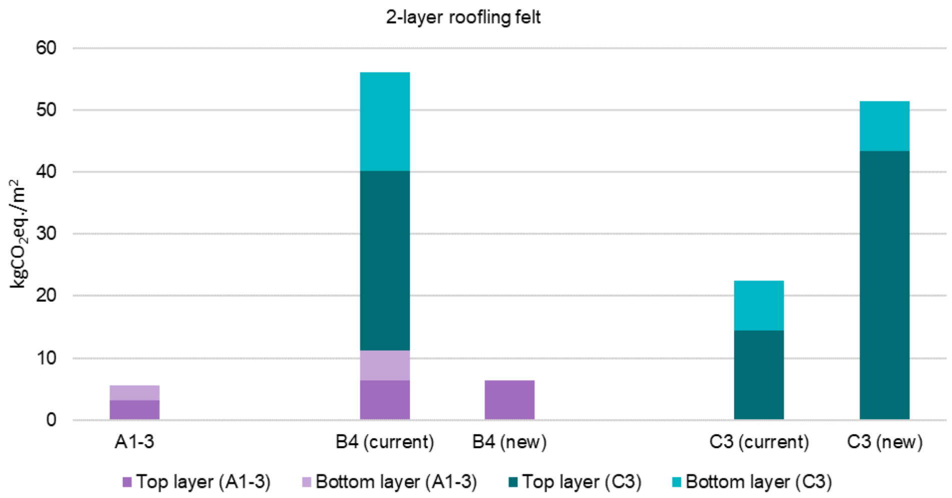


FIGURE 11: Climate impact change in B4 module when a replacement procedure closer to the real practice (new) is simulated for roofing felt (Data sources: generic Danish data in BUILD report 2023:15 (Kragh & Birgisdôttir, 2023)).

It is important to note that in the case of EPDs this approach to roofing felt replacement is reported in either B4 or B5. Furthermore, there are occasions this is reported in a different unit than normally (per year of use). Care must be taken when such values are directly used.

2.2.7 Elevators

Energy consumption for indoor transportation can account for around 5-10% (Karlis, 2014) (De Almeida, Hirzel, Patrão, Fong, & Dütschke, 2012) of the total operational energy consumption in function of building energy efficiency. The range of relative importance will be different in the case of carbon footprint as different types of energy will affect the environment differently, but still significant.

Some countries have now started including this type of energy use in their requirements as default values. One example is the German label Qualitätssiegel Nachhaltiges Gebäude (QNG) (see **Figure 12** for reference values).

Energy efficiency class	Load kg	Speed m/s	Use category of elevator (kWh/year)				
			1 0,2h	2 0,5h	3 1,5h	4 3h	5 6h
A	630	1,0	527	661	1.106	1.774	3.110
		1,6	583	800	1.523	2.608	4.779
B	630	1,0	1.008	1.205	1.864	2.853	4.829
		1,6	1.091	1.414	2.490	4.104	7.333
C	630	1,0	1.946	2.237	3.207	4.662	7.572
		1,6	2.071	2.550	4.146	6.540	11.327
D	630	1,0	3.788	4.213	5.632	7.760	12.015
		1,6	3.975	4.683	7.040	10.576	17.648
A	1600	1,0	670	1.018	2.177	3.915	7.393
		1,6	811	1.371	3.236	6.035	11.631
B	1600	1,0	1.222	1.741	3.470	6.065	11.253
		1,6	1.434	2.271	5.060	9.243	17.611
C	1600	1,0	2.267	3.040	5.616	9.480	17.208
		1,6	2.585	3.835	8.000	14.248	26.745
D	1600	1,0	4.270	5.418	9.245	14.987	26.469
		1,6	4.746	6.610	12.821	22.139	40.774

FIGURE 12: Default B6.2 values provided in the German label QNG, Appendix 3[3].

2.2.8 Other products

It is expected that building-integrated carbon capture solutions will start increasingly being seen and applied as a solution to achieve carbon neutrality for the whole life cycle of buildings without the need for carbon removal offsets outside the building's boundary. This will significantly affect B1/B6, and potentially also B2. Other innovative products whose life cycle effect is now unknown may have similar effects. Therefore, modules which may currently appear as insignificant in a relative sense, may increase in importance. For example, there is already an HVAC-integrated carbon capture solution produced by a Nordic company which converts buildings into atmospheric CO_2-capturing machines (Soletair Power Carbon Capture Environmental Engineering Company in Finland). The CO_2 captured from a building can be used to make products. These future possibilities should be considered in the overall discussion about expanding the current assessment scope.

[3] Source: pg. 18 of the current manual, available at https://www.qng.info/app/uploads/2023/04/QNG_Handbuch_Anlage-3_Anhang-3212_LCA_Anforderung-NW_v1-3.1.pdf

2.3 Influence of extending the scope in 10 cases

This section analyses 10 cases for different building types to examine the influence of including an extended life cycle scope (A4, A5, B1, B2-3, C1, C2), as well as other data on B4, on the total climate impact. Thus, it examines how much it is estimated to move the climate impact.

The data used to prepare the calculations comes from DGNB-certified projects, external projects and life cycle assessments carried out by BUILD as part of different projects. The case buildings included in this report were constructed between 2015 and 2022. To account for differences between buildings, it was attempted to include a broad selection of cases with different qualities in terms of building types, sizes, materials, etc. (see **Table 9**).

Furthermore, it was ensured to select cases that include detailed data on the technical installations, to the extent possible, as they are expected to have an influence on B1 and B2 modules as discussed in Section 2.2.2. Other cases considered as likely interesting particular for the missing modules are prefabricated buildings (which are normally associated with lower A5 impacts), heavy concrete buildings (which potentially increases the carbonation effect in B1) and buildings with vegetated surfaces (which could affect B1 depending on whether the vegetation is included in the system boundary and how it is calculated). At least one of these special cases was included in the building sample.

However, it should be noted that no assessment has been made as to which case buildings are the most representative of the Danish building stock. **Table 9** shows a code for each building type to make it easier to identify the building types included in the results. Some of the cases form part of the BUILD report 2021:12 *Whole life carbon assessment of 60 buildings* (Zimmermann, Andersen, Kanafani, & & Birgisdottir, 2021), while other cases have been analysed as part of the BUILD report 2023:10 *Whole Life Carbon Impact of: 45 Timber Buildings* (Andersen, et al., 2023). However, changes, such as in building model definition and data, have continuously affected the results of the life cycle assessments, which means that the results in BUILD report 2021:12 cannot be directly compared with results constructed according to BR18 (2023). In addition, further changes are assumed to occur up to BR18 (2025). These changes include a significant decrease in B6 due to the introduction of new emission factors. These changes are explained in the BUILD report 2023:21 *Klimapåvirkning ved nybyggeri: Analytisk grundlag til fastlæggelse af ny LCA baseret grænseværdi for bygningers klimapåvirkning fra 2025* (Tozan, et al., 2023).

TABLE 9. Summary of the main characteristics of the 10 building cases.

Building type	Code	Source	Project	Year	Area [m²]	System with refrigerant	Type of construction[a]
Commercial building(s)	1ER *(hotel)*	VSC	Green solutions house	2021	1034.5	Ventilation unit with heat recovery (10000 m³/h)	Heavy
	2ER *(hospital)*	SBi	60 cases (A08)	2015	19518	Air-conditioning system (76 kW) + Air-water heat pump (11 x 7 kW)	Heavy
Apartment building(s)	3EB	External	60 cases (E10)	2018	2592	-	Heavy
	4EB	External	45 wooden cases (Studio[Home] Lyngby)	2020	17530	-	Light
Detached houses	5EKR	SBi	60 cases (Enf09)	2016	178.5	Ground heat pump (10 kW) + Ventilation unit with heat recovery (430 m³/h)	Light
Terraced houses	6EKR	DGNB	60 cases (R02)	2017	1954	Water-water heat pump (4x10 kW)	Light
Offices	7KB	DGNB	60 cases (K04)	2018	6375	-	Heavy
	8KB	SBi	60 cases (K16)	2016	12944	Air-conditioner (600 kW)	Heavy
Institutional buildings	9IN	External	Unpublished (Vrå Børne- og Kulturhus)	2022	9630	Ventilation unit with heat recovery 9700 m³/h	Light
	10IN	External	45 wooden cases (Karolinelund Børnehave)	2020	859.5	Ventilation units with heat recovery 1600 m³/h + 6400 m³/h	Light

[a] In line with the 60 cases report, the differentiation between heavy and light buildings is related to the load-bearing structures, where heavy buildings have internal walls or concrete elements, and light buildings have skeleton frames. The differentiation is independent of the type of façade cladding used.

Building parts included

In the data collection, the building parts included in the analyses across the 10 building cases consist of foundations, basement slabs and slabs on grade, external walls, load-bearing structures, inner walls, roofs, stairs/steps and ramps, balconies and patios, windows, doors and glass façades, drains, water pipes, heating, ventilation and cooling systems as well as electrical and mechanical systems (among other things). Other elements such as paving or channels under the ground, lighting, or small elements like fasteners were omitted.

Reference service life and replacement of construction products

A reference study period of 50 years is used. The reference study period affects the replacement of construction products. Construction products with a shorter service life than the reference study period must be replaced one or several times during the reference study period. In this project, service life for the individual building parts is based on BUILD's Service Life Table version 2021 (Haugbølle, Mahdi, Morelli, & Wahedi, 2021). In this study B4 also includes associated impacts for transport to site in module A4.

Climate databases for products

Climate impact data basis in Building Regulation BR18 (2023) can be either generic data from Annex 2, Table 7, or valid and relevant environmental product declarations (EPDs) in accordance with DS/EN 15804. The current version of Appendix 2, Table 7 (version 2, 20.12.2022) in BR18 is constructed with data from Ökobaudat 2020 II (DS/EN15804+A1), which is not always accurate for construction products in Danish construction, and selected industry EPDs for concrete and wood products. In this project, the climate impact of the cases for the modules in the current scope (A1-3, B4, C3-4) is calculated based on an updated version of generic data for use in Annex 2 Table 7 from the year 2025 developed as part of a parallel project and published in BUILD report 2023:15 (Kragh & Birgisdôttir, 2023). The focus of this parallel project was on compiling generic data for typical standard construction products that are often produced in Denmark and used in new buildings such as bricks, roof tiles and plasterboard. The procedure involved collecting EPDs for construction products produced in Denmark and using them as a base to determine a new level of generic data.

For construction products where neither Danish data nor Danish industry EPDs exist, Ökobaudat 2023 I (DS/EN 15804:2013+A2:2019) is used. The particular datasets selected are provided in an Excel document accompanying the BUILD report 2023:21 *Klimapåvirkning ved nybyggeri: Analytisk grundlag til fastlæggelse af ny LCA baseret grænseværdi for bygningers klimapåvirkning fra 2025* (Tozan, et al., 2023).

Valid product-specific EPDs when included in the cases by consultants have been used instead of generic values for the calculation in this project. This sets a realistic level of emissions for the individual building according to how it is built today.

Concerning B1 data, these were obtained from the Danish industry EPDs for concrete products when available. For products like cement-based mortars and fiber cement boards where industry EPDs are not available, B1 values were taken from product specific EPDs or industry EPDs from other countries instead. While the combination of generic data and product-specific data to fill the gaps within the same product is not a generally recommended approach in practice, this was necessary for the purposes of this study. A similar approach to filling some of the gaps when an important effect was expected has also been also used for other types of products to compensate for the lack of B2 values in main data sources used. A general overview of the data availability for the missing modules is provided in section (2.4). When compensating for the missing data it was made sure to select specific products which closely match the density and/or thickness (among other characteristics) provided for the product of the same type in the generic Ökobaudat dataset.

Some examples of product-specific EPDs used are given in **Table 10**. This Table also offers a first glimpse of some of the challenges for B2 consideration on the basis of EPDs from different EPD providers; B2 is a module that includes the frequency of performing a specific activity, thus, values sometimes reflect the annual impact, other times they represent the cumulative impacts along a reference service life other than 50 years. Furthermore, there are cases where B2-related impacts are shared among B2 and B3 modules.

TABLE 10: Examples of datasets used from product-specific EPDs and Ökobaudat version 2023-I to fill gaps for B1 and B2 calculation.

Product type	EPD used to fill gaps	Module used
Fibercement board	Troldtekt A/S – MD-22046-EN	B1: -0.534 kgCO_2eq./m^2 (if unpainted)
Ceramic/stoneware tiles	Keramische Fliesen und Platten Bundesverband Keramische Fliesen e.V – EPD-BKF-20220184-ICG1-DE	B2: 0.1703 kgCO_2eq./m^2 (EPD result adjusted to 50 years, as well as multiplied by 13 when applied to floor)
Wooden floor, stave parquet	Longlife parquet – average data, Ökobaudat	B2: 5.394 kgCO_2eq./m^2
Aluminium door T30/EI30	Hörmann KG Eckelhausen - Feuerschutztür T30 – specific data, Ökobaudat	Used in its entirety as no generic data are available B2: 38.6 kgCO_2eq./m^2 (sum B2 + B3)
Green roof	Urbanscape® Green Roof System – S-P-05961	B1: -61.5 kgCO_2eq./m^2

C1 values were only available for concrete, ceramic and metal products. For other products C1 is considered negligible and therefore the missing values were not substituted with average values.

Database for operational energy

The climate impact of operational energy consumption in module B6 is calculated based on updated emission factors (Sørensen, Høibye, & Enersen Maagaard, 2023) for the 2025 version of the Building Regulation. These factors are reduced by 38% and 78% for electricity and district heating, respectively, compared to the ones currently applied in BR18 (2023) (Bolig- og Planstyrelsen, 2022). The values are shown in **Annex A**.

Calculation assumptions for new modules and adapted replacements

A4 (transport) and A5 (construction process)

Module A4 can be calculated in three ways:

(a) using a weighted distance factor (kgCO2eq./ kgkm) multiplied by the weight of the building materials and a distance for each building material including return trips;

(b) using a fuel factor (kgCO2eq./ kg of fuel), and multiply by the amount of fuel consumption if known;

(c) using a product-specific factor (kgCO_2eq./ functional unit) i.e. from EPD where the A4 impact factor for a product can be multiplied by the quantity of this product.

The third approach can be the simplest one when A4 data in EPDs is available. Yet, transport impacts depend on the location of the project. Transport information in EPDs can be useful but often do not indicate the actual transport conditions, but a generic value of 50 or 100 km, which must be scaled with project-specific information. To enable an approximate calculation of A4 in construction projects and reduce the workload associated with handling data from different EPDs, there is a need for national reference values for significant product groups. These values can be included as an estimate of the building's overall climate impact during project development, but also as a generic value for documentation. As a project develops, the documentation should be supplemented with more project-specific transport, for example for the materials that are most significant in A4.

In this sense, within the context of the REBYG project national reference values for product groups have been developed to reflect a typical transport distance from factory to Danish construction sites (BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023)), see **Annex B.** The base is information provided in EPDs combined with, where possible, specific transport statistics from the last years in an industry or major suppliers. Missing data was supplemented based on estimation of the location of production. The route of imported goods was calculated with Odense as a central distribution in Denmark, where hub locations were unknown. For overseas imports, transshipment is assumed in the port of Hamburg, unless otherwise stated. Transport for technical building installations is generally based on an estimated distance of 500 km due to a lack of data for this complex product group. A further development of the references, enriched with more data and possible simplification is expected in the future.

It must be noted that while for the nine of the ten cases the above-described approach was used to estimate A4, for case 01ER, all invoices or delivery notes for construction goods are available. This allowed a calculation of A4 based on specific transport conditions. Concerning A5, the reference value of 1.30 kgCO_2eq./m^2/year developed in REBYG project is used as a default. This value represents the 75% percentile based on consumption data for electricity, fuel and heating, and waste from 46 recent Danish construction sites (38 originate from outreach work and 8 are test projects that were submitted on the evaluation platform for the voluntary sustainability class). This reference value is adjusted for missing consumption data which was the case for some of the studied data. It also includes two additional aspects that were not measured; 0.06 kgCO_2e/m^2/year as a standard value for driving away soil, and 0.06 kgCO_2e/m^2/year representing the disposal of construction waste.

Only for the prefabricated case building 4EB a value of 0.55 kgCO_2eq./m^2/year was applied assuming that no or little waste is generated on site (the 75% percentile of construction waste associated emissions is 0.753 kgCO_2eq./m^2/year and is subtracted from the value of 1.30 kgCO_2eq./m^2/year). It should be noted that the off-site assembly of prefabricated products typically is considered in A3, while A5 only includes installation. Therefore, in theory, the waste in the factory should be included in A3, however, it was not considered in this project due to lack of data.

B1 (use)

For air-conditioner systems the fugitive emissions caused by refrigerants were modeled by assuming an emission flux in the air of R134a fluid, with an annual leakage rate of 5%. The quantity of the refrigerant charged was considered 0.25 kg per kW cooling capacity as a rule-of-thumb (UN Environment, 2022). For heat pumps, a leakage rate of 2% of R410a refrigerant was assumed and a charged quantity of 1.6 kg. **Table 11** summarizes the different calculation assumptions for fugitive emissions applied to the 10 cases.

TABLE 11: Assumptions applied for the calculation of climate impact due to refrigerant leakage during building use (B1).

System type	Annual leakage rate[a] (% of charge per annum)	Refrigerant	Charge
Air-conditioner	5%	R134a	0.25 kg/kW
Heat pump 10 kW	2%	R410a	1.6 kg [b]
Ventilation with heat recovery 10.000 m^3/h	2%	R 407C	14.5 kg [b]

[a] selected based on rates proposed by the German Federal Ministry (UBA) (2.5-5% depending on the system), CIBSE (CIBSE, 2021) (2-6% depending on the system) and the French Regulation RE2020 (2% is used as default value when specific data is unavailable)
[b] selected based on the specifications of similar products in the Danish market (i.e. Adersen Electric heat pumpts, Nilan ventilation units, etc.)

To cover the carbonation effect associated with each building case, for ready-mix concrete and other concrete elements B1 values were taken from the industry EPDs. For cement screed no available B1 value was identified in either Okobaudat or EPDs, therefore, the typical average value for uptake of 25 CO_2/m^3 proposed by the technical standard DS/CEN/TR 17310:2019 was used. For cement- and lime-based mortars used for different purposes in the building cases the value of -0.108 $kgCO_2eq/kg$ was used for reasons of simplicity as it represents an average of a wide range of products and recipes for mortars (ranges for % cement, lime, sand, etc.) (see **Table 7**). As Danish EPDs for mortars that include B1 are growing, the creation of generic values would be possible as part of a future version of Table 7, Appendix 2 of BR. All B1 values were multiplied by 0.7 to convert to 50 years service life. It is important to note that the effect of carbonation and hence B1 values were assumed as being reduced by 30% when walls were covered by paints. This is the approximate difference observed in the k factor in **Table 6** from values “with cover” and values “without cover”. Therefore, the following formula was used:

$$B1_{50} = B1_{100}\ \textit{(value from EPD)} \times 0.7\ \textit{(conversion to 50 years)} \times 0.3\ \textit{(covered with paint)}$$

B2 (maintenance) and B4 (replacement)
To be in line with the current PCR for windows and door sets DS/EN 17213:2020 as well as to achieve a smooth transition from the use of generic data in early design stages to product-specific EPDs later in the process, the replacement of glass was considered in B2 instead of B4. This was done only in the cases where these subproducts were replaced earlier than the frames; for example, the glass of internal windows is not replaced at all during the buildings’ service life. Paint is now also considered in B2 instead of B4. The B2 share representing the glass replacement and the repainting does not capture newly added impacts but reallocated impacts and thus is referred to as “B2 (re-alloc.)” from here on.

The B2 share that represents the new additions is called “B2 (new)”. In the case of windows and glass surfaces the impacts related to the consumption of cleaning agents and water are part of this. A detailed calculation of this impact would necessitate multiplying the quantities of the cleaning agents and/or oils used by the related impact factors and the number of applications for the service life of the window. However, this study did not perform such a calculation and instead applied an approximate impact value of 2.5 $kgCO^2eq./m^2$ of glass surface based on French data on windows obtained from INIES. A value towards the upper end was chosen among the ones available in order to be conservative. Values from INIES were chosen instead of values from other countries, as the assumptions used in INIES regarding the quantity of cleaning agents and water used for cleaning are closer to the assumptions used in some Danish product-specific EPDs including B2 (e.g. see Ventisol windows). For the cleaning and maintenance of other surfaces (e.g. lacquering and/or oiling of wooden floors) values were taken from some product specific or average EPDs where reasonable (examples previously shown in **Table 10**) and converted to a 50 year-service life when needed.

B2 calculation also includes the filter replacement in ventilation and air conditioning systems. This was possible by using an EPD for a typical filter among the few available (e.g. Camfil filters). For example, the number of replacements assumed for a ventilation unit were 48 given that there will be no filter replacement when the whole system is replaced in the middle of the building's life cycle and is disposed at building's EoL. Finally, B2 includes refrigerant refills when 10% of the overall quantity leaks, i.e. for a 2% annual leakage rate, eight fluid refills were considered over the service life[4].

B6 (Elevator electricity consumption)

Based on the new electricity emission factors shown in Annex A (Sørensen, Høibye, & Enersen Maagaard, 2023) and a yearly energy consumption of 1864 kWh for the operation of a class B elevator (**Figure 12**) – which is the minimum requirement in BR18 – and of an average use and speed, the climate impact is 54 $kgCO_2eq./yr$. All the building cases in this report that include an elevator are above 1000 m^2, which leads to a contribution of less than 0.06 $kgCO_2eq./m^2/yr$ in this study. Since the share is very small and the current version of EN 15978 standard recommends that this type of consumption shall be reported separately, the effect of B6 for elevators is not shown or analysed further in this study.

C1 (deconstruction) and C2 (transport)

C1 values were only available for concrete, ceramic and metal products in either generic data or specific EPDs. For the remaining products C1 is considered negligible and therefore the missing values were not substituted with average values. C2 values are available for most of the products which means that no development of specific assumptions was necessary.

Results

This section shows the results for the 10 building cases at a 50-year reference study period in the unit kg CO_2-eq/m^2/year. **Figure 13** shows the climate impacts for the case buildings distributed on the different life cycle modules, starting from the modules in the current scope – A1-3, C3-4, B6, B4 (minus the glass replacement) – and adding the missing modules as moving to the left for a more complete whole life coverage. Furthermore, B1 and B2 modules are divided into their most important constituents to gain a better insight of the details. Particularly, B1 is divided into the share attributed to the refrigerant losses "B1 (refrigerant)", the carbonation effect "B1 (carbonation)", and carbon sequestration due to vegetation "B1 (vegetation)".

Three building cases do not include any refrigerant-related impacts, 3EB, 4EB and 7KB, as they are connected to the district heating system and do not include any heat pump, any air conditioner or ventilation system with heat recovery. All buildings include a certain level

[4] The number of refills is defined by deducting the two entire system replacements (no refill takes place) from 10.

of carbonation but as several cases are wooden buildings, this is often invisible due to its marginal share. Only 10IN includes a green roof and the related negative B1 share.

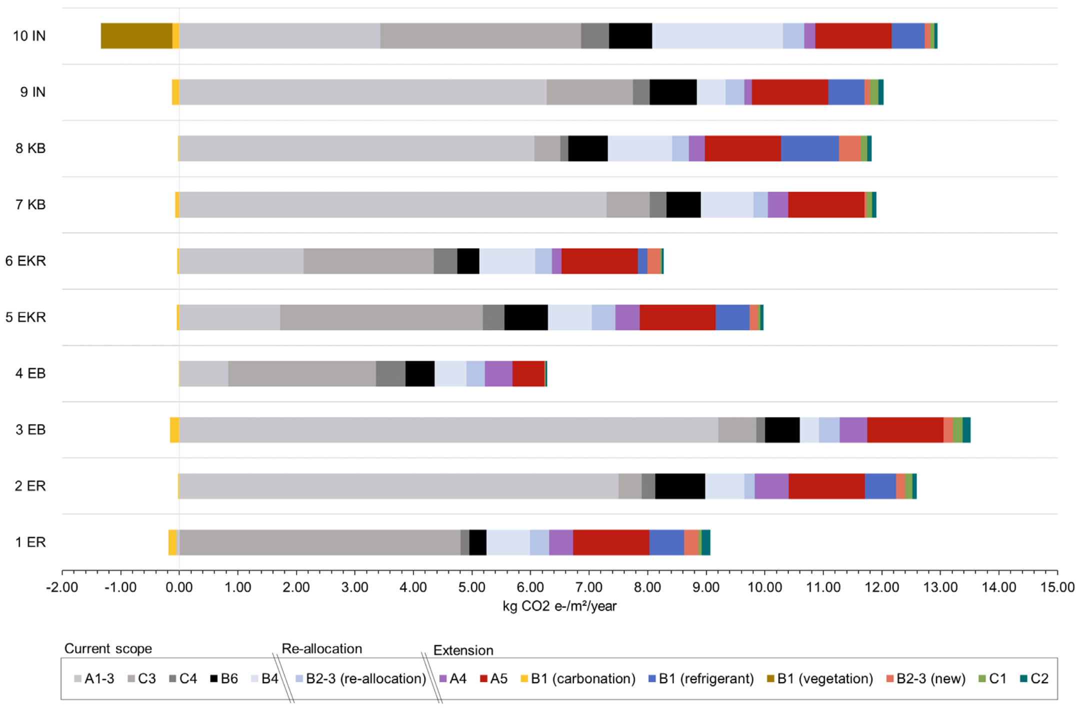


FIGURE 13: Overview of the life cycle impact in $kgCO_2eq./m^2/year$ per building case and module for a 50-year RSP.

In the case of B2, this is divided into the following two shares: the share representing the impacts of repainting, previously reported under B4, and glass replacement, still reported under B4 but with a potential to be moved to B2 if requested by the upcoming revised EN 15978, and the share representing maintenance impacts not yet accounted for in the Danish assessment scope. The former share does not capture newly added impacts but reallocated impacts and thus is indicated as “B2 (re-allocation)” whereas the latter share is new addition and thus is shown as “B2 (new)”.

In general, **Figure 13** shows that the highest absolute contribution of the new modules to the current scope is seen for the office building 8KB at a level of more than 3.10 $kgCO_2eq/m^2/yr$. On the other hand, the lowest effect of the added modules is for 10IN for “B1 (vegetation)” included, and the prefabricated accommodation building 4EB for “B1 (vegetation)” excluded. If the negative shares of B1 were not accounted for, the new modules would represent on average 22% (including the re-allocated part) of the whole life cycle climate impact (**Figure 14**). The related median share is 24%.

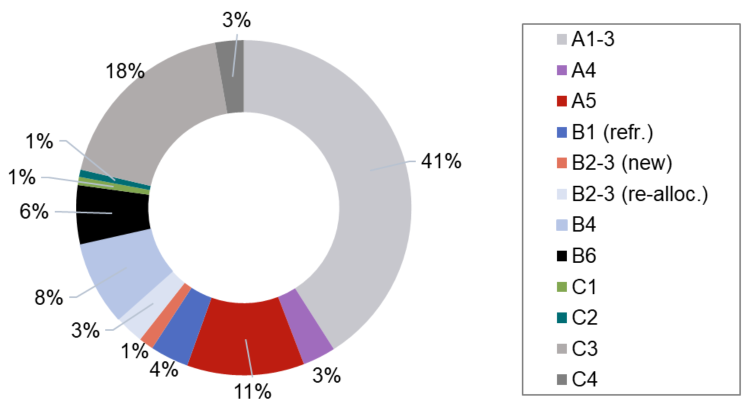


FIGURE 14: Relative mean contribution of the modules to the total climate impact.

Figure 15 shows the distribution of the results and that, on average, missing modules can shift the overall median climate impact result by 2.77 $kgCO_2eq/m^2/yr$. In general, the biggest addition to the average is the module A5 which was taken as a default value of 1.33 $kgCO_2eq/m^2/yr$, while the second biggest contribution is B1 module due to the impacts of refrigerants (**Figure 16**). The latter contributes more than 0.55 $kgCO_2eq/m^2/yr$ to the overall climate impact of the buildings that include relevant systems, with the highest value reaching close to 1 $kgCO_2eq/m^2/yr$.

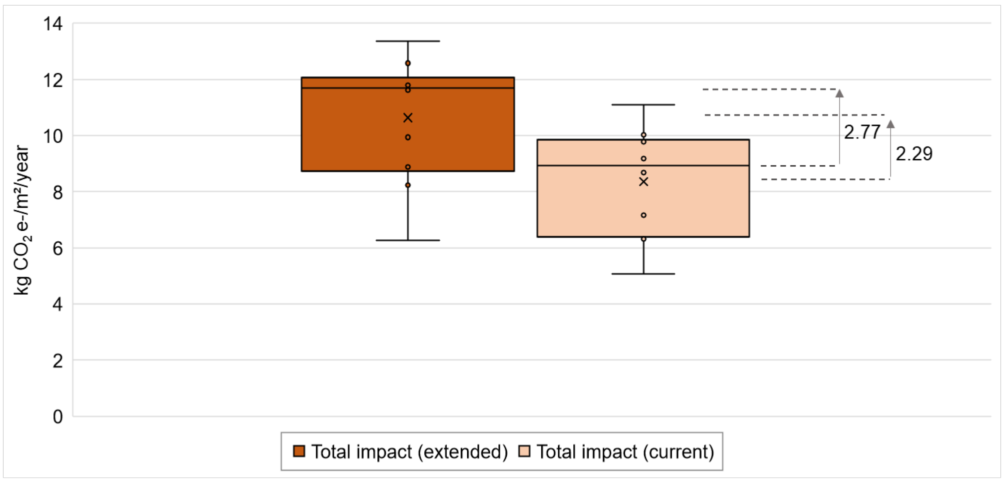


FIGURE 15: Comparison of the range of the new lifecycle impact results that represent an extended scope (A1-3, A4-5, B1, B2-3, B4, B6, C1-2, C3-4) vs the current scope (A1-3, B4, C3-4) based on 10 building cases of various types. The median climate impact for the former is 11.70 $kgCO_2eq./m2/year$, while for the latter 8.93 $kgCO_2eq./m2/year$.

On the other hand, carbonation of cement- and lime-based products in the selected building cases offsets up to 0.15 $kgCO_2eq/m^2/yr$ which corresponds to a concrete apartment building, and roughly 1% of the total impact, aligning with findings of other studies (e.g. (Alig, Frischknecht, Krebs, Ramseier, & Commissioners, 2020).

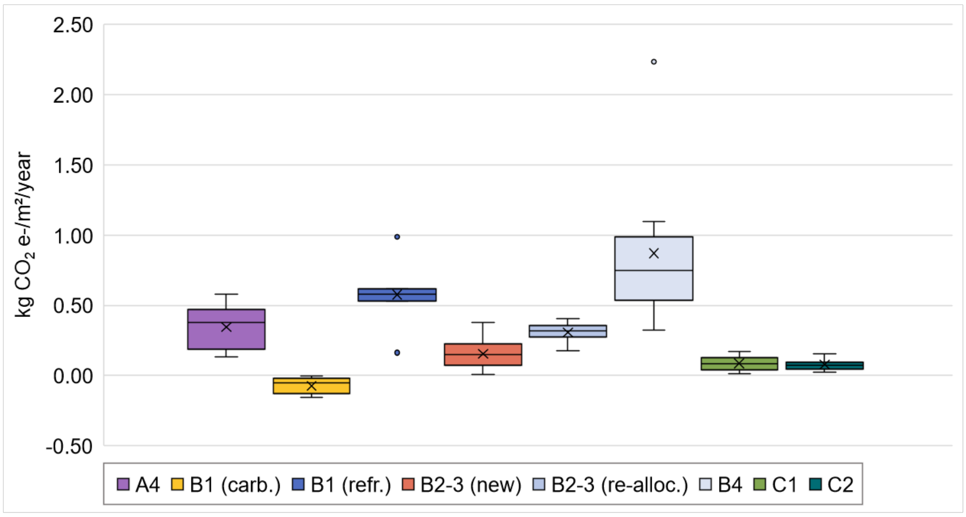


FIGURE 16: Ranges of missing modules from the current scope (A4, B1, B2-3, C1, C2) and new results on B4 (recalculation with subtraction of glass replacement of windows and paintwork) based on 10 building cases of various types. Note: Construction site impacts (A5) and the effect of carbon sequestration due to a green roof (B1(veg.)) are not in the graph as they constitute single values in this study.

In the case of B2-3, 67% of its effect can be attributed to the reallocation of glass replacement in windows, doors and facades and paintwork (total B2-3: 0.46 $kgCO_2eq/m^2/yr$). In relation to how B4 changes, on average, one fourth of B4 impacts are now moved to B2. If glass replacement is not re-allocated, the B2 only for paintwork accounts for 0.09 $kgCO_2eq/m^2/yr$ on average. Both B4 and B2-3 (re-allocation) include the transport impacts. Finally, C1 and C2 modules add, on average, only a very small portion to the total, i.e. 0.16 $kgCO_2eq/m^2/yr$ collectively.

Table 12 provides more details on the different quartile values generated from the analysis of the 10 cases. Considering the calculation effort vs extent of impact of several of these modules, the generation of reference values for some of them would be a recommended approach so that they can be used in the case of missing data.

TABLE 12: Quartile values for climate impact in $kgCO_2$-eq/m^2/year for the missing use stage and end of life modules B1, B2, C1, C2. B1 value for vegetated is not included as it has only been considered in one building case. Note: Reference values (quartiles) for A4 based on the analysis of nine of the cases of this project are provided in BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023) and are 0.247, 0.408 and 0.469 $kgCO_2eq/m^2$/year. The same report also provides reference values for A5 but based on the analysis of real data from 50 construction sites, not connected to the cases analysed in this project.

	kgCO₂eq/m²/year					
Quartile	**B1**		**B2-3**		**C1**	**C2**
	Carbonation	**Refrigerant**	**New**	**Re-allocation**		
Lower quartile (25%)	-0.13	0.53	0.08	0.28	0.04	0.05
Median (50%)	-0.05	0.58	0.15	0.32	0.08	0.07
Upper quartile (75%)	-0.02	0.62	0.23	0.36	0.13	0.10

2.4 Expected workload and economic consequences for data collection and calculation

2.4.1 Data availability in generic databases and industry EPDs

If the short-term calculation of A4, A5, B1, B2, C1 and C2 is required, generic data must be provided. **Table 13** summarises the data availability particularly in ÖKOBAUDAT database release 2023-I as of 15.06.2023 (indicated as "GenDK") as well as in industry EPDs available in Denmark as of early May 2023 (indicated as "EPDDanS").

TABLE 13 Non-exhaustive overview of data availability for the missing modules identified in the generic and average datasets of ÖKOBAUDAT database (release 2023-I as of 15.06.2023) (indicated as "GenDK") and in industry EPDs available in the Danish EPD system (indicated as "EPDDanS") Note: by negligible a contribution of ≤ 5% to A1-3 (or C3 in the case of biogenic products) is identified.

Module	***Available for…***	***GenDK or EPDDan***	***Product-level importance***	***Value and approx. % contribution (if ≥ 5%)***
A4	WPC cladding profiles	GenDK	Negligible	
	DPL laminate flooring	GenDK	Negligible	
	Natural stone slab, rigid, indoor usage	GenDK	Non-negligible	6.79 $kgCO_2$eq./m^2 *(22.6% A1-3)*
	Wood products (various types)	EPDDanS	Non-negligible for CLT	42.4 $kgCO_2$eq./m^3 *(5.6% of C3 incineration)*
	Ready mix concrete (various types)	EPDDanS	Negligible	
	Shuttering blocks	EPDDanS	Non-negligible	5.49 $kgCO_2$eq./tonne *(6% of A1-3)*
	Precast concrete elements (various types)	EPDDanS	Negligible	
A5	EPS insulation (various densities)	GenDK	Negligible	
	Metal ceiling systems	EPDDanS	Negligible	
	Facade paint	GenDK	Negligible	
	Indoor paint	GenDK	Negligible	
	Solid wood parquet (German average)	GenDK	Negligible	
B1	Ready mix concrete (various types)	EPDDanS	Non-negligible for low strength concrete	see examples of % contribution in **Table 7**
	Precast concrete elements (various types)	EPDDanS	Negligible	
	Shuttering blocks	EPDDanS	Non-negligible	-5.86 $kgCO_2$eq./tonne for 50-year RSP *(6.5% of A1-3)*
	Concrete paving blocks	EPDDanS	Non-negligible	-1.25 $kgCO_2$eq./m^2 *(9% of A1-3)*
	Refrigerants	GenDK	Non-negligible	Can add more than 200% to the total (A1-3, B4, C3-4) of heat pumps and other systems depending on the scenario assumed.

Module	*Available for…*	*GenDK or EPDDan*	*Product-level importance*	*Value and approx. % contribution (if ≥ 5%)*
B2-3 (new)	Multi-layer parquet	GenDK	Non-negligible	7.037 $kgCO_2eq./m^2$ *(55% of C3)*
	Tufted wall-to-wall carpet (German average)	GenDK	Non-negligible	0.385 $kgCO_2eq./m^2$ *(7.3% of A1-3)*
C1	Ready-mix concrete	EPDDanS	Non-negligible	E.g. see **Figure 5**
	Other concrete products (e.g. aerated concrete, etc.)	GenDK and EPDDanS	Negligible	
	Metals (e.g. reinforcing mesh)	GenDK	Negligible	
	Facing brick	GenDK	Negligible	
	Ceramic tiles	GenDK	Negligible	
C2	Almost all products	GenDK and EPDDanS	Negligible	

Table 13 shows that most Danish industry EPDs include A4 data as they are easy to provide based on an average weighted distance from different production sites to a furthest hypothetical location in Denmark. The only industry EPDs that do not include A4 (and A5) are for non-residential ventilation units and ducts and windows. On the other hand, ÖKOBAUDAT does not provide A4 values for most types of products. Even if provided, they would not represent the Danish market as the assumed distances would be based on the situation in Germany.

A great lack of data availability for main construction products can be observed for A5 module. This is justifiable since the product manufacturer does not know for what kind of building the product will be used. Instead, generic databases tend to provide data on either different type of construction processes such as pumping of concrete or excavation (e.g. ÖKOBAUDAT), earthwork and soil stabilization (e.g. Finish generic database[5]) or focus on providing the waste associated with different types of products which forms part of A5 (Climate database from Boverket[6]) and rely on reference values for the on-site energy consuming processes. In principle, A5 must not use EPD data but rely on measurements from the site (as opposed to A4). In Denmark, data availability is secured through the provision of reference values in the BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023).

For B1 data, there is a wide availability for concrete products but not for autoclaved aerated concrete and mortars. Here a need to complement the gaps with product-specific values is identified. Regarding the carbonation effect of cement- and lime-based mortars, the lack of generic B1 values makes it challenging to include it in the calculation. A way

[5] See: https://co2data.fi/rakentaminen/

[6] See: https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/

forward could be to develop preliminary generic values based on the growing number of B1 values available in product-specific EPDs by applying a conservative approach, i.e. apply an uncertainty factor. Providing these values to the industry will reduce the workload associated with searching for product-specific data considerably. Furthermore, even when B1 data is provided, the coverage of exposure scenarios is limited to maximum two. In relation to refrigerants, impact data is available in kgCO_2eq./kg of refrigerant for various types but data for this aspect in the building systems themselves are not to be found.

Concerning the new B2-3 impacts, missing generic data are observed for windows, while data are available for only two types of flooring and/or walling: parquet and carpet. This is no surprise since maintenance is highly dependent on the needs of the specific product. A greater availability of B2 values is expected when looking at the specific products.

Availability of C1 is limited to some main product types like concrete, reinforcement and bricks which usually constitute the load bearing part of a building and are usually bonded together by binders; therefore, they need a range of tools and equipment to deconstruct them. However, similar to A5, generic building level values for C1, like the ones provided in Finland's generic database would make more sense than product-specific values. Conversely, C2 data, despite their relative low contribution to the impact, are widely available and most are constructed by assuming a short distance to the waste treatment or landfill.

2.4.2 Data availability in EPDs

Product-specific EPDs often have a wider availability of data on new modules considering that many processes such as transport, installation and maintenance are better specified by the manufacturers themselves. There is product specific EPDs in the Danish system already providing such data and potentially be used in future for generating generic values as its number is growing.

For example, already about 75% of product specific EPDs include A4 module (based on BUILD's internal research[7]). Types of products for which it has been observed that A4 is predominantly missing are slag gravel, stones and sand, other individual concrete ingredients like fly ash, concrete paving flags, windows and glass wall systems, some insulation materials, wooden flooring systems, plasters, as well as district heating units, among others.

In respect to B1 all concrete products include B1, and from spring 2023 more and more product-specific cement- and lime-based mortars have also started including B1. This provides a good opportunity to create B1 generic values also for mortars in future. Regarding B2, examples of EPDs including values are only for carpets, some windows and glass systems, BIPV Modules and rain gutter systems. Developing a simple calculation method or generating generic values based on B2 values from other EPD systems would be necessary if B2 is included in the scope.

[7] based on BUILD's internal documentation of available EPDs by Emilie Brisson Stapel as of February 2023

2.4.3 Expected workload and economic consequences

General scenario as a base to estimate the time needed to document new modules
This part is focused on the missing modules B1, B2, C1 and C2. The expected workload and economic consequences for A4 and A5 are discussed in the report BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023).

The starting point for the assessment is that there is a requirement for only reporting modules B1, B2, C1 and C2 without a limit value for all new buildings in the building regulations from 2025 in accordance with recommendations in this report. This will entail additional administrative costs to produce the necessary documentation, while costs for design or construction will not be affected. Specifically, costs will stem from time spent preparing projects to better translate data provided by building product and system manufacturers, contractors and craftsmen, but also facility managers, into robust building level scenarios.

The amount of time spent on documentation is significantly affected by two factors: the availability of data and the method of documentation. As data is always generated and stored by the provider of the service in question, availability is determined by whether the provider shares the data with the consultants in sufficient quantities and in a usable format, even though it is not requested by legal requirements. However, the first players have already developed ways to make this data available. The scenario behind the time spent by the consultant must therefore estimate the extent to which the supplier will make the requested data available or whether the consultant must actively collect and process this.

Second, the time consumption depends on which documentation method is adopted. Here, what is decisive is the extent to which the client may use possible standard values in the building regulations for documentation that directly affects time consumption. Using default values for an entire module or aspect within a module (e.g. B1 carbonation) will not incur any time consumption. To explore a conservative approach, in the following scenarios, this possibility is not included in the calculation. Instead, it is assumed that all projects provide at least partially specific documentation. Standard values are assumed to be used only for certain input parameters into some of the needed calculations in the sense that they need to be defined by the method. The approach thus shows economic consequences when the use of standard values for entire modules is restricted when the requirement is introduced or in a later tightening.

It is also assumed that tools are available for the collection and reporting of B1, B2, C1 and C2 when the requirement comes into force. Therefore, the time consumption does not include the development of tools or climate calculation, but only the collection and processing of data and the preparatory investments in the value chain. Furthermore, it is assumed that introduction of a mandatory requirement is accompanied by the provision of generic impact values needed for the calculation of those modules in Annex 2, Table 7 of the BR18, e.g. for main types filters, carbonation of main types of cementitious elements and products, generic cleaning agents and lacquer or oil, among others.

Scenario for carbonation (B1)

Specific documentation for this effect would require assigning exposure conditions to the various building elements that can be subject to carbonation, i.e. painted/unpainted, exposed to outside air/internal, above ground/below ground/underwater, etc. This type of information can be obtained from the building model, and it is assumed that rearranging it in a useful format for B1 calculation will require some additional effort. The associated time investment can be assumed to increase with the number of surfaces for which carbonation needs to be calculated. It is estimated that the effort per affected surface will not exceed a few minutes (on average) for an experienced consultant.

This workload does not include a possible need to adjust B1 values already provided in industry and product specific EPDs. As mentioned in previous sections, impact factors for B1 carbonation are nowadays increasingly provided by manufacturers for concrete products, however, typically including one or two geometric and locational scenarios (thickness and location in the building). Developments in this area include examples of EPDs from other countries like Sweden with B1 values given for multiple use scenarios, indicates that this can also be the case for Denmark in future. Therefore, it is expected that by 2025 as the assumed year of the introduction of this requirement, more B1 values covering various scenarios will start being provided, as well as main conversion factors from one exposure condition to the other. This means that the effort one would need to invest in readjusting the B1 values given in EPDs to suit a particular project's characteristics will be close to zero as it will only involve multiplying already given impact values with given factors.

Additionally, since in most cases this effect can only offset about 1% of the total building's climate impact, the B1 computation procedure can tolerate a certain degree of approximation.

Scenario for refrigerant losses (B1, C1)

The documentation effort of refrigerant losses involves collecting and processing data for the heat pump, ventilation, or air-conditioning systems to be installed in a building with respect to the quantity and type of refrigerant in each system. This information is already part of the publicly available technical specifications of the various manufacturers in the market. It also normally forms part of facility management manuals as refrigerants need to be refilled if above a certain amount is lost during use. Therefore, additional time consumption to obtain this information can be considered close to zero. It can also be assumed that the calculation and documentation workload for this effect is not influenced by the size of the building.

The annual leakage rate during use and percent of leakage occurring at the end-of-life are parameters which can only be provided as default values by the method and constitutes no effort for the consultant.

Carbon sequestration of vegetated surfaces (B1 or A1-3 + C4)

There is no consensus yet on where this effect must be reported. This has up to now led to various allocation approaches within EPDs and generic databases. It is assumed that the introduction of documentation requirement for this effect will be supported by the provision of generic values per m2 of vegetated roof and surface and specific rules about where and how this must be documented. For example, this can be documented separately like module D until a European-wide consensus about allocation is reached. Furthermore, even if EPDs follow a different allocation method than what regulation will require, with the provision of GWPbio (which should be in place in all EPDs by 2027) the workload needed for adjustments can be assumed as negligible.

Scenario for maintenance (B2)

The amount of time invested in documentation of cleaning and maintenance of different types of floor/wall surfaces and products with glass surfaces such as windows, curtain walls, doors and skylights, depends on the number of scenarios that need to be defined. The greater the variety of products that need maintenance are applied to the building the more scenarios will have to be specified and calculated. This means that the documentation workload does not vary with the type of building, but it can be assumed that it increases with the variety of surfaces and products installed in a building subject to maintenance. What changes with the type of building is the frequency of maintenance. For example, a hospital would need more frequent cleaning than a commercial building, and a residential building much lesser cleaning than both.

Important to note is that painting of surfaces and replacement of glass in windows and doors do not count as an additional workload as they are already accounted for in LCAs; the effort of reallocating from B4 to B2, if recommended by the future standards, is assumed as zero.

Since maintenance schedules are product specific, the scenarios will have to be based on information reported in product specific EPDs, if reported at all, or information on proper maintenance provided by the manufacturers. The latter will have to be translated into useable formats (schedules and quantities of consumables). EPDs currently provide maintenance-related information in various forms and units: Some EPDs provide annualized information, others provide the quantities and number of applications needed for the whole service life of a product which can be other than 50 years. Furthermore, some EPDs provide more than one maintenance scenario to choose from, other EPDs state that the schedules and quantities provided are meant for residential buildings or a particular area of installation (e.g. tiles can be installed onto both floors or walls which influences the chosen scenario, i.e. walls are less frequently cleaned than floors). Therefore, the documentation requires the user to carefully convert the provided information and/or B2 values into a project's specific conditions. It is assumed that in the light of an upcoming documentation requirement for this aspect in 2025, manufacturers will be encouraged to include such information in their EPDs among other sources, along with possible conversion factors to represent various scenarios. It also is estimated that an experienced consultant will need no more than a few minutes per type of surface and product to locate the right information and adjust the B2 values accordingly after a first short phase-in period. It can also be the case that parts of the needed information is already available in life cycle cost documentations, if in place.

For filter replacement, specific documentation would require collecting and processing data on the quantities and types of filters in the ventilation and air conditioning systems used, as well as replacement cycles from the system manufacturers. This type of data typically must already form part of facility management manuals and in most cases the frequency of replacement is taken as once per year as a default. Therefore, as the filter-related data is either already in place or easily obtainable, the documentation effort is estimated as close to zero.

Scenario for deconstruction (C1)
To accurately calculate C1 would necessitate to use project specific scenarios or adjust EPD values accordingly since there may be a disparity between the EPD and project end of life scenario. However, as deconstruction takes place in the far future, the request for additional effort associated with detailed calculations would be unreasonable. It is assumed that standard scenarios and values for some of the processes like demolition or deconstruction for different levels of application of Design for Deconstruction (DfD) principles will be provided by the regulation which will reduce the additional effort close to zero.

Scenario for transport at End of Life (C2)
Similar to C1, C2 would necessitate the definition of various default scenarios by the method for different types of products. It is assumed that these scenarios will be limited to only a few main ones (e.g. consider one default distance to the waste processing/landfilling site and one type of vehicle or the average distance to the two closest waste processing/landfilling sites) due to the high speculative nature of this module. This reduces the time investment needed for this module close to zero.

Economic model
The calculation uses the same basic model as described in BUILD report 2023:21 (Tozan, et al., 2023), including time consumption in hours and hourly cost rates. In the following, the specific conditions that only apply to the calculation of the modules B1, B2, C1 and C2 are explained. The economic model of the modules A4 and A5 is presented in BUILD report 2023:14 (Kanafani et al. 2023).

The starting point with a factor of 1.0 is year 5 (2027), where it is assumed that a form of routine in working with the requirement at a level that can be observed today with the leading players on the market. For example, Annex C outlines the number of hours the construction industry must invest in the documentation of requirements for a standard single-family house (150 m^2).

The calculation covers the years 2023-29, which is why additional costs are zero the first two years before the entry into force of the new requirements, see **Table 14**. In years 3-4, a phase-in period is expected with up to 100% higher time consumption and investments for documentation. On the other hand, costs are expected to fall by 10% in the two subsequent years 6-7 as a result of a general streamlining. This is due to an increasing scope of routine data provision in useful and harmonized formats from suppliers and clarification of responsibilities in agreements with contractors.

TABLE 14. Time consumption for documentation of modules B1 and B2 where the number of hours depends on the size of the building in the 3rd year from the entry into force of the requirement (factor 1.0).

Building size, m²	65	70	75	80	90	100	120	150	180	200	250
Time consumption, hours	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8
Building size, m²	500	750	1,000	1,500	2,000	3,000	5,000	10,000	20,000	30,000	40,000
Time consumption, hours	1	1.1	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.1	2.2

The costs are estimated on the basis of the new construction in the 6-year period 2015-2020, as can be seen from the registrations in BBR. Future construction activity is generally expected to be on a par with construction activity in the period 2015-2020. The overall new construction activity broken down by building use and by ownership is shown in Tables 10 and 11 of the BUILD report 2023:21 (Tozan, et al., 2023). **Table 15** and **Table 16** below show additional costs divided by the building's use and ownership respectively. Year 3 refers to the year 2025, if the requirement is introduced.

TABLE 15. Costs of documentation of B1and B2 in DKK distributed on building uses (without VAT).

	Factor	**0,00**	**0,00**	**2,00**	**1,25**	**1,00**	**0,90**	**0,80**
Code in BBR	**Year**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
110	Single-family houses	0	0	73,000	45,000	36,000	33,000	29,000
120	Detached houses	0	0	1,515,000	947,000	758,000	682,000	606,000
130	Terrace houses	0	0	826,000	516,000	413,000	372,000	330,000
140	Apartment buildings	0	0	837,000	523,000	419,000	377,000	335,000
150	Colleges	0	0	28,000	18,000	14,000	13,000	11,000
160	Other institutions	0	0	72,000	45,000	36,000	32,000	29,000
190	Other residences	0	0	24,000	15,000	12,000	11,000	10,000
220	Production buildings	0	0	182,000	114,000	91,000	82,000	73,000
320	Office and trade	0	0	463,000	289,000	231,000	208,000	185,000
323	Warehouse	0	0	175,000	109,000	87,000	79,000	70,000
330	Hotel and service	0	0	82,000	51,000	41,000	37,000	33,000
410	Culture	0	0	60,000	37,000	30,000	27,000	24,000
420	Education	0	0	148,000	93,000	74,000	67,000	59,000
430	Health centres	0	0	42,000	26,000	21,000	19,000	17,000
440	Daycare centres	0	0	66,000	41,000	33,000	30,000	26,000
490	Barracks or prison	0	0	23,000	15,000	12,000	10,000	9,000
520	Summer houses	0	0	44,000	27,000	22,000	20,000	17,000
530	Sports	0	0	127,000	79,000	63,000	57,000	51,000
	Sum	**0**	**0**	**4,787,000**	**2,990,000**	**2,393,000**	**2,156,000**	**1,914,000**

TABLE 16. Cost of documentation of B1 and B2 in DKK divided by type of ownership (without VAT).

Code in BBR	Factor	0.00	0.00	2.00	1.25	1.00	0.90	0.80
	Year	1	2	3	4	5	6	7
10	Private person	0	0	2,021,000	1,263,000	1,011,000	909,000	808,000
20	Public utility	0	0	262,000	164,000	131,000	118,000	105,000
30	Company	0	0	1,582,000	989,000	791,000	712,000	633,000
40	Association	0	0	250,000	157,000	125,000	113,000	100,000
41	Housing cooperative	0	0	5,000	3,000	2,000	2,000	2,000
50, 60	Commune	0	0	259,000	162,000	129,000	116,000	103,000
70	Region	0	0	40,000	25,000	20,000	18,000	16,000
80	State	0	0	39,000	24,000	19,000	17,000	15,000
90, 99	Others	0	0	327,000	204,000	164,000	147,000	131,000
	Sum	**0**	**0**	**4,785,000**	**2,991,000**	**2,392,000**	**2,152,000**	**1,913,000**

3 ANALYSIS OF HANDLING THE NEW MODULES IN SELECTED COUNTRIES

The analysis in this chapter contains an overall description of how countries that have implemented requirements for the climate impact of buildings require the content of the modules analyzed in **Chapter 2**. The analysis covers the countries which currently have existing or ongoing processes for binding climate declarations: the Netherlands, France, Norway, Sweden and Finland.

In addition to these country regulations, the new London Plan mandatory methodology on whole life carbon is presented where relevant. Although not a national regulation, it affects a big part of UK’s population as well as it can be expected that any similar future regulatory requirements in the UK will draw lessons from this initiative.

The analysis is based on published material on the countries' handling of A4, A5, B1, B2, C1 and C2 modules, as well as by contacting relevant persons with expert knowledge about the life cycle scope and its details in the countries covered by the analysis.

Results from the analysis are collected in a systematic way in table(s) and/or figures with associated descriptions.

3.1 General overview

The reviewed regulations differ in scope of assessment. Some of the regulations require a whole life cycle assessment, such as in France and the Netherlands, while Sweden has a narrower scope that is only limited to upfront carbon emissions from A1 to A5. **Figure 17** presents the modules included in the life cycle scope that must (or expected to) be considered in the climate declaration and/or limit values for each of the reviewed regulations, following the modular structure of EN 15643 (CEN, 2021). It should be noted that the scopes indicated in Finland and Sweden for future declarations and limit values constitute proposals (as of September 2023) and not final decisions.

Table 17 shows some general non-technical information of the regulations. It indicates when the regulation came into or is expected to come into force, which building types it applies to and which data sources are allowable for use.

Table 18-**22** show the details of how each new module is handled in the selected countries. Particularly, **Tables 18-19** are adapted from the BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023) which provides a more extensive analysis of A4 and A5 modules.

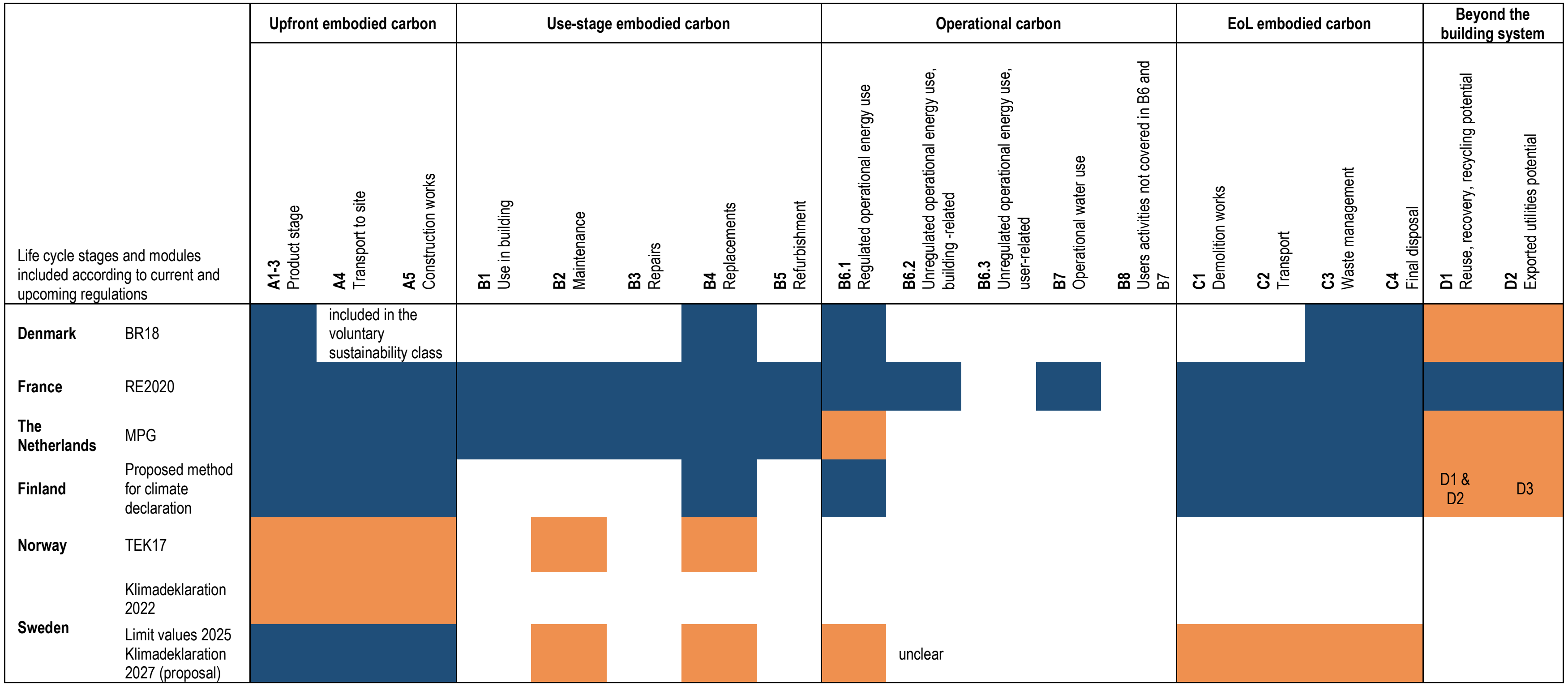


FIGURE 17: Overview of the life cycle scope covered in selected countries in Europe with regulation already in place or expected to come into force. Note: "blue" denotes the scope in limit values and "orange" in climate declaration. In Finnish method D1-D5 constitute the carbon handprint, with D5 covering carbonation but only beyond the system boundary.

TABLE 17. General information on the methodology of each selected country

Country	Methodology	In force since…	Applies to…	Allowable data sources
Netherlands	MPG	2013	Residential, office (above 100m^2)	NMD (strictly)
France	Réglementation environnementale RE2020	2022	Residential, office, all educational buildings (no minimum applicable size)	INIES database
Finland	Building Act (adopted on 1 March 2023)	Will enter into force on 1 January 2025	All building projects applying for a construction permit. Exemptions exist such as special purpose buildings e.g. industrial and religious buildings	National database co2data.fi or EN 15804+A2 compliant data
Norway	NS 3720 / TEK 17	2022	Residential and commercial buildings	EPD Norge and EN 15804 compliant data
Sweden	Climate declaration 2022	2022 Limit values expected to enter into force in 2025	All building projects above 100 m^2 Sweden provides detailed requirements on which buildings are exempted from declarations and are independent of the building type[2]	Boverket and EN 15804 compliant data
UK	London Plan and Part Z proposal[1].	London Plan already in force since 2022, Part Z is still a proposal	All building projects above 1000 m^2 or 10 dwelling units	The Built Environment Carbon Database (BECD) is under development.

[1] based on RICS Professional Statement “Whole life carbon assessment for the built environment” 2017 edition – a revised version is currently available which has been subject to a commenting period
[2] see: https://www.boverket.se/sv/klimatdeklaration/vilka-byggnader/inte-deklareras

TABLE 18: Module A4- overview of existing definitions.

	Finland	**Norway**	**Sweden**	**Netherlands**	**France**	**UK**
Default value on building level (per m²)	27 $kgCO_2e/m^2$	No	No	No	No	No
Default values on process or parameter level	Additional emission factors for different means of transport with varying utilization depending on road resistance	Concrete 50 km, other goods 300 km plus possible imports	Generic values for energy and fuel for A4 and A5 Generic values for A4 and A5 per material weight Background for generic values: - Distribution 1.0 MJ/ton km - Delivery 1.5 MJ/tonne km	Bulk material 50 km Other building materials 150 km Specific calculation for imports (to Utrecht when destination is unknown)	-	Locally manufactured (ready-mixed concrete) 20 km Locally manufactured (general) e.g. aggregate, earth 50 km Nationally manufacture e.g. plasterboard, pre-cast concrete 300 km European manufactured (Central and Eastern Europe) e.g. CLT 1,500 km European manufactured (Scandinavia and Western Europe): 300 km (road), 800 km (sea) Globally manufacture e.g. specialist stone cladding: 500 km (road), 10,000 km (sea)
Transport included	Not equipment	Only for building materials and waste, but not packaging, interim and other materials	Only essential building parts incl. packaging (according to other phases) Not equipment and removal of soil	Not defined further	Building materials	Building materials

	Finland	Norway	Sweden	Netherlands	France	UK
Utilization rates	Outward: not determined Return: 0%	Outward: not determined Return: Not determined	Outward: not determined Return: 0%	Outward: not determined Return: 0% (or specific)	Outward: not determined Return: Not determined	Outward: not determined Return: 100% sea or rail, 0% road
Reporting	Specific calculation	1. EPD, must be converted to specific distance 2. Simplified calculation with Euro 5 truck 16 – 32 tonnes with 50% filling level (transport calculator on lca.no) and standard emission factors	1. Based on actual fuel consumption 2. Calculation based on weight, distance and means of transport 3. Simplified calculation based on weight 4. Detailed calculation	-	-	Project-specific evidence from the main contractor and subcontractors when becomes available.

TABLE 19: Module A5- overview of existing definitions

<table>
<tr><th></th><th>Finland</th><th>Norway</th><th>Sweden</th><th>Netherlands</th><th>France</th><th>UK</th></tr>
<tr><td>Default value on building level (per m^2)</td><td>Office 78 kg $kgCO_2e/m^2$
Housing 46 $kgCO_2e/m^2$
School, institutions 60 $kgCO_2e/m^2$
The upper values exclude earthwork: 7 kg CO_2e/m^2</td><td>No</td><td>No</td><td>No</td><td>No</td><td>Divided into three distinct processes:
Pre-construction demolition 50 $kgCO_2e/m^2$
Construction activities 25 kgCO2e/m^2
Site waste $5kgCO_2e/m^2$</td></tr>
<tr><td>Default value on process and parameter level</td><td>Soil stabilization: 0.04 kgCO2e/kg (stabilizer)</td><td>Waste: Generic data from recognized tools</td><td>Waste percentages for all construction products, incl.
Liquid concrete 3%
Rocks/blocks: 5%
Building boards: 10-12%</td><td>Waste share (construction waste):
Prefabrication: 3%
Insitu 5%
Surfaces etc. 15%</td><td>Simplified calculation rules for SFH and other buildings, based on parcel size, crane usage, etc.</td><td>Waste percentages for various material/ product types</td></tr>
<tr><td colspan="7">Scope of included energy and water usages, and construction waste</td></tr>
<tr><td>Electricity</td><td rowspan="3">Yes, only purchased energy</td><td rowspan="4">Module A5 is not covered (except for waste)</td><td rowspan="3">Yes, but not for off-road work</td><td rowspan="4">Unspecified</td><td rowspan="4">Yes</td><td rowspan="4">Energy consumption for site accommodation and plant use without further specification of a minimum scope</td></tr>
<tr><td>Heat</td></tr>
<tr><td>Fuel</td></tr>
<tr><td>Water</td><td>No</td><td>No</td></tr>
<tr><td>Construction waste</td><td>Yes</td><td>Production of waste
Production of packaging is assumed to be included in A1-3
Interim and other materials not included</td><td>Yes, but only material waste and only from essential building parts
Wastage can also be used from EPDs</td><td>Yes</td><td>All waste, also during transport, is allocated in A5
Waste scenarios can be either generic or specific</td><td>Influences are included in the EPD</td></tr>
</table>

	Finland	Norway	Sweden	Netherlands	France	UK
Transportation	Removal of waste	No	Only transport on site No waste disposal	Removal of waste	Yes	Removal of waste and excavated soil
Reporting	Either standard values or specific calculation National emissions data or data from other recognized sources may be used	Waste will normally be calculated as the difference between delivered and estimated material quantity, for example in tender programmes	Waste will normally be calculated as the difference between delivered and estimated material quantity, for example in tender programmes	A5 is often not included in practice	Many optional indicators can be reported, including amounts of hazardous and non-hazardous waste generated.	Preference over site-specific data when available

TABLE 20: Module B1- overview of existing definitions. Note: Finland does not include B1 module in its scope but carbonation is part of the so called "carbon handprint".

	Finland	Netherlands	France	UK (London)
Default value on the building level	No, only on process/aspect level (next rows)	No	No	No
Carbonation	Considered in handprint D5: 0.021 kgCO2e/kg	Included in B1 and fixed in the national database	Included in B1 and fixed in the national database	Included in B1 and C3/C4 based on data from EPDs or equivalent sources, provided that the conditions in the scenario selected in the data source coincide with the anticipated project-specific ones in relation to exposure[1].
Refrigerants	No	User-defined scenarios	Yes (section 4.2.1.1.6 of the decree). B1 and B2 are taken directly from INIES and if not included in some related systems a formula provided in the regulation must be used, together with the default leak rate of 2%	User-defined scenarios with a recommendation to CIBSE TM65 methodology
Vegetation (net sequestration)	No, according to latest developements	Out of scope	No specific requirement	RICS: Yes, for green roofs and facades of more than 1,000 m^2 wih the precondition that this is supported by relevant evidence, e.g. landscape consultants' report.

[1]If the assumptions are either not sufficiently transparent or diverge from what is expected to apply to the specific project being assessed, carbonation figures should either not be taken into account or adjusted accordingly. Detailed guidance on calculating and reporting the carbon uptake from carbonation is given in EN 16757.

TABLE 21: Module B2- overview of existing definitions for the relevant countries.

	Norway	Netherlands	France	UK (London)
Default value (building or product level)	Neither default values nor values from generic databases shall be used (for product level)	No	No, but B2 default values for different types of products are fixed in INIES	10 $kgCO_2e/m^2$ gross internal area (GIA) or 1% of modules A1-A5, (whichever is greater)
Paint	Yes	Not specified	Not specified	Part of B4, with service lives 10 years for paint and 30 years for render
Glass replacement (windows, glass doors)	Yes, for windows and glass doors with an estimated lifetime that is at least as long as the building's calculation period, any replacements of insulating glass panes	On the product level, important parts of a product to be replaced are under B4 in NMD database	No, windows and doors (frames + glass) have a 30 years default service life and considered in B4; glass is not replaced earlier than the frame	Same as in France
Filter replacement	Building services may be omitted (not part of the minimum scope)	Yes	Not seen in default values provided by INIES for related systems	Yes if data is available
Cleaning and maintenance of different surfaces	Yes, for wooden and other external surface products that require regular surface treatment in the form of painting oil treatment and the like	Cleaning maintenance is only included if functionally important (user-defined)	Fixed in INIES	Yes if data is available, otherwise use of the default value
Vegetation fertilisers and others	Out of scope	Out of scope	Fixed in INIES	Disposal of any waste biomass from the maintenance of green roofs and facades
Possible data sources	- EPD or other equivalent third-party approved sources - Own simplified calculation based on maintenance intervals as stated in SINTEF instruction 700.320 - Detailed own calculations with documentation of the choices made	Only NMD	Only INIES	A detailed list of allowable sources per design stage is provided in the new draft updated version of RICS (Appendix B) – in future BECD

TABLE 22: Modules C1 and C2- overview of existing definitions for the relevant countries.

	Finland	Netherlands	France	UK (London)
Default value for C1 or C2 *(building level or product level)*	C1: Office building 14 kg CO_2e /m^2 Residential building: 7 kg CO2e /m^2 School or kindergarten: 9.8 kg CO_2e /m^2	No	No, Default values are provided for various products for the entire end-of-life (C1-4)	C1: 3.4 kgCO_2e/m^2 GIA (derived from monitored demolition case studies in central London) to be used in the absence of more specific information
Default scenarios for C1	Future emission reductions for different forms of energy are considered	It depends on the product	It depends on the product	C1 values as a % of A5, are given considering three demolition/ deconstruction scenarios: business-as-usual (25%), good practice (30%), best practice (50%). Future decarbonsation will be considered. Refrigerant leakage impact when decommissioning the systems at end of life, following the CIBSE TM65, should be accounted for in C1.
Default scenarios for C2	load rate is assumed to be 100% on the outward journey and 80% on the return journey.	50 km distance	It depends on the product	In the absence of specific information, average distance from the two closest reclamation/ waste processing facilities/landfills to the project site. Assumed mode of transport: an average rigid HGV with 50% load to account for the vehicles coming to site empty and leaving with 100% load.
Possible data sources	EPDs or default value	Only NMD	INIES	A detailed list of allowable sources per design stage is provided in the new draft updated version of RICS (Appendix B) – in future BECD

3.2 Netherlands

This section is based on the "Environmental Performance Assessment Method for Construction Works, Version 1.1"[8] (March 2022), "Guide to environmental performance calculations" (July 2020)[9].

General overview of regulations and limit values

Construction in the Netherlands is regulated by the Dutch Building Decree. According to national regulations, the national methodology Milieu Prestatie Berekening (MPG) is mandatory for all new residential buildings and office buildings above 100 m^2 (public or private). From 2024 the regulation will expand to all types of buildings, including renovation and transformation. A maximum limit value for the LCA results has been applied to all MPG assessments as of 1 January 2018, given as a shadow price and initially set to 1.0 €/m^2/year. From 1st of July 2021 the limit value for residential buildings was tightened.

Brief intro to the national LCA methodology and database

The nationally used methodology MPG is based on a Dutch determination methodology that bases calculations on the European EN 15804 +A2 standard. The scope of the assessment is limited to materials found in the national NMD database and includes the whole life cycle of the building, excluding the operational part (B6, B7). The NMD contains information about products formulated in accordance with MPG in the form of product cards that refer to environmental profiles.

Handling of A4, A5, B1, B2-3, C1 and C2

Standard scenarios are provided for modules for which simplification would be useful to reduce the workload. For example, standard values apply with respect to transport distances to avoid unnecessary discrepancies between products when calculating the overall performance, as well as because of the assumed small contribution of A4 to the total impact. However, for the tendering, detailed data on transport are required. For A5, the consideration of the different types of energy uses on the product level becomes complicated as typically the product manufacturer does not know for what kind of building the product will be used. Therefore, this is often left open. For waste, standard values for 'loss in the form of construction waste' distinguishing between three categories are defined: Prefab products, In-situ products, and auxiliary and finishing materials. MPG does not provide default scenarios for calculating B1, B2 and C1. For example, data on concrete carbonation is taken from the product level. For C2 the typical distance assumed is 50 km.

[8]Source: https://milieudatabase.nl/media/filer_public/89/42/8942d5dd-8d37-4867-859a-0bbd6d9fb574/bepalingsmethode_milieuprestatie_bouwwerken_maart_2022_engels.pdf

[9] Source: https://milieudatabase.nl/wp-content/uploads/2020/09/Guide_to_environmental_performance_calculations_July_2020.pdf

3.3 France

This section is based on chapter 4 of the French decree Arrêté du 4 août 2021[10] (where the RE2020 regulatory calculation method is described).

General overview of regulations and limit values

The French Decree on energy and environmental performance requirement for building construction is the official regulation for calculating and limiting the climate impact of building in France. It applies to all residential, office, and primary or secondary educational buildings, regardless of the size, that are subject to a building permit from 1st of January 2022 onwards. It is expected to extend to other typologies. The limit values set in the decree are decreasing over time and divided into two broad categories: the “ICconstruction_max” that cover A1-5 modules and the “ICenergie_max” which is for life cycle carbon emissions that are related to energy consumption. The limit values vary dependent on various parameters such as typology, building area, location, etc.

Brief intro to the national LCA methodology and database

RE2020 is the regulatory calculation method in France. What differentiates this method from EN 15978 is the application of a dynamic calculation principle where a coefficient to each year from year 1 to year 50 for the considered RSP is employed. The methodology covers the full scope including module D in the total result. The French national database INIES includes both generic data as well as EPDs compliant with EN 15804.

Handling of A4, A5, B1, B2-3, C1 and C2

The scope covered in the French method follows closely the standard EN 15978. The scenarios used for handling A4, A5, B1, B2, C1, C2 modules are fixed in the national database INIES and depend on the product type. However, especially for calculating the contribution to the environmental impacts of the building construction site the use of specific project data is required as well as a submission of a calculation note that explains how this data was collected or obtained by calculation. Furthermore, for the case of refrigerant impact, its inclusion is mandatory. If data is not available in an EPD, the regulation provides a formula to be used.

[10]Source: https://www.legifrance.gouv.fr/download/file/LBxKOX3Duk3h0j_ck_WBwvf9HBYDu3aSYhPKEIm97w4=/JOE_TEXTE

3.4 Finland

This section is based on the draft methodology for assessing the climate impacts of buildings published by the Finish Ministry in 2021 (Kuittinen M. , 2019). The final updated version of the methodology is expected to be published following the new Building Act.

General overview of regulations and limit values

The new Building Act will require a mandatory climate declaration for all projects when applying for a construction permit. However, certain projects like very small buildings or buildings of special functions are exempt from this requirement. Alongside the mandatory declaration, Finland may also introduce mandatory limits in 2025. The limit values are expected to exclude underground and external site constructions.

Brief intro to the national LCA methodology and database

Finland's climate declaration covers a broad scope in its methodology (A1-A3, A4, A5, B4, B6, C1-C4). It prioritises product specific data, however, to facilitate the process, the Finnish Environmental Ministry has created a national database (co2data.fi) in cooperation with the Finnish Environmental Institute. The database provides generic values for most used construction materials as well as default values for different types of processes. The local EPD program operator is RTS.

Handling of A4, A5, B1, B2-3, C1 and C2

The methodology handles the challenges associated with stages requiring the use of scenarios by providing default values, i.e. for construction processes A4 and A5, as well as the EoL stages C1, C2 and C3-4. For construction and demolition, default values distinguish between office buildings, residential buildings, school or kindergarten, as well as separate values are provided for earth work and stabilization.

The default values provided represent mean values based on carbon footprint calculations for building life cycles previously made in Finland, with an additional 20% uncertainty factor. However, if the product to be used in the building is known, product specific information is prioritized.

A special feature of the Finnish method is the requirement to express both a building's carbon footprint and "carbon handprint", with the latter including the concrete carbonation effects.

3.5 Norway

General overview of regulations and limit values

The special energy and greenhouse gas emission chapters in the Norwegian building regulation TEK 17 (Kommunal- og distriktsdepartementet, 2022) came into force on 1st of July 2022, with a one-year transition period after which they have become mandatory. The plan on when to introduce limit values is still open.

Brief intro to the national LCA methodology and database

TEK 17 is based on the national building methodology prescribed in the standard NS 3720, which is based on the EN 15978 standard. While the methodology includes the whole life cycle of the building, the regulation solely requires the calculation of A1-A3, A4, A5 and B4. EPD Norge is the program operator including a vast number of EPDs, and no generic database or national database is recommended in case no specific EPD value is available.

Handling of A4, A5, B1, B2-3, C1 and C2

A5 is currently limited to emissions related to the production and transport of materials that become waste. Energy used for construction processes is excluded. Examples of emissions excluded are emissions from excavation and blasting, emissions from mobile and stationary work machines, and emissions linked to operation of the building site with heating, ventilation, drying and lighting. Own calculations are accepted for modules A4, A5, B2 and B4 and can be simplified based on default values e.g. for transport distances. However, the use of generic data is not acceptable.

3.6 Sweden

General overview of regulations and limit values

The new national act on climate declaration for buildings which governs embodied carbon reductions in the building sector entered into force 1st of January 2022. All newly built buildings over 100 m^2 subject to a building permit are obliged to submit a climate declaration. Exceptions exist such as for industrial buildings or buildings used for defence or agriculture. According to the latest proposal by Boverket in 2023 (Boverket, 2023), limit values may be introduced on 1 July 2025 at the earliest, in the regulations on climate declarations for buildings. Stages B, C and D are not proposed for inclusion in the limit value from 2025. However, modules B2, B4 and B6 are expected to be included in an expanded climate declaration from 2027 in order for the calculation to visualise various trade-offs that may have an effect on deciding on products or design solutions: i.e. trade-offs between low initial climate impact (A1-3) and the maintenance needs of the products and building design (B2), the lifespans of products (B4), an energy-efficient building envelope (B6). Inclusion is also proposed for stage C in the extended climate declaration, with the primarily reason being to provide a more complete picture of the climate impact of a building over its life cycle, and to underline recyclable products.

Brief intro to the national LCA methodology and database

The climate declaration focuses solely on upfront carbon emissions (A1-5) at the moment. Product-specific data are prioritised, but if not found for the specific product used, generic data in the national database provided by Boverket can be used.

Handling of A4, A5, B1, B2-3, C1 and C2

Sweden deals with A4 and A5 modules by providing generic national database values. However, waste on the building site shall be estimated with project specific values or specific carbon emission data provided by the manufacturer.

3.7 United Kingdom (UK)

General overview of regulations and limit values

UK's national Building Regulations do not yet regulate the whole life cycle emissions of a Building, however, the construction industry has proposed a new amendment to existing UK Building Regulation, called "Part Z" (Arnold, Dekker, Giesekam, Godefroy, & Sturgis, 2022). The proposal introduces both, a mandatory assessment starting from 2023 and the setting of carbon limits to be introduced later on.

Although not a national regulation, the Greater London Authority has set mandatory requirements for whole life assessments on the basis of the RICS methodology and related benchmarks in its London Plan (Greater London Authority, 2022).

Brief intro to the national LCA methodology and database

RICS published an updated methodology in 2023 (2nd edition) which extends to cover all buildings and infrastructure throughout the built environment life cycle and will be effective from 1 July 2024 (RICS, 2023). At the same time, various organisations operating across UK have collaborated in developing the Built Environment Carbon Database (BECD) which will constitute the base for any type of date needed for carbon calculations and assessments. A first version of BECD was released in autumn 2023[11].

Handling of A4, A5, B1, B2-3, C1 and C2

RICS methodology provides detailed default scenarios for every post-A1-3 module, which scenarios have been further refined in the new version of 2023. For example, in the method to be effective from early 2024, for A4, six different default transport distances are given, i.e. (1) for locally manufactured ready-mixed concrete, (2) for locally manufactured general products, (3) for nationally manufactured products, (4) for Central or Eastern European manufactured products, (5) for Scandinavia and Western Europe and (6) for globally manufactured products. For post-completion assessments, A4 transport should be modelled based on actual information on material quantities used, distance from the supplier, vehicle loading, empty return and fuel consumption data, if known.

In the case of the in-use module (B1), this is considered with a subdivision into three sub-modules: carbonation and other removals (B1.1), emissions from materials (B1.2) and fugitive emissions of refrigerants (B1.3). For the annual refrigerant leakage from equipment the accounting method as detailed in CIBSE TM65 (CIBSE, 2021) is recommended.

[11] Version 1.0.0 can be accessed here: https://carbon.becd.co.uk/

4 SUMMARY OF BENEFITS AND DRAWBACKS OF AN EXTENDED SCOPE

The review and updating of the limit values for 2025 and 2027 poses an opportunity to revisit the scope of the methodology itself as it has a significant impact on the carbon footprint of the national construction sector. The benefits and challenges of extending the current scope of the methodology and the limit values are discussed below.

A4 and A5 modules

The inclusion of A4 and A5 modules in the short-term future regulatory limits is essential for the following reasons: the industry can have an immediate influence on both, and the consequences can be measured and documented directly at building's handover. Furthermore, the impact of A5 can be significant. Including them will drive the market to select local construction products if available, reduce empty runs, and develop solutions that can achieve significant carbon impact reductions on site. If a requirement is placed, an allowance to use a fixed default value for the first years can be a solution until more experiences are gained, however, with the precondition that every project documents an accurate result in the meantime.

B1 module

Carbonation of cement- and lime-based products is a well-documented phenomenon. It provides an opportunity to offset emissions, however, this effect is negligible in most cases, and consequently the implications of inclusion/exclusion from a climate perspective seems to be small (in most cases this effect can only offset about 1% of the total building's climate impact). Moreover, carbonation beyond a certain level is not desirable in reinforced concrete; it may have adverse effects (corrosion) on the robustness of the embedded steel bars. Carbonation rates depend on the duration of exposure, concrete designation and the exposure conditions including any concrete surface treatments. Therefore, carbonation predominantly affects exposed concrete elements and mortar whose surfaces are untreated/uncoated. The time-effort related to calculating this effect relates to defining which concrete surface layers are exposed and how and is estimated to be low. As manufacturers are increasingly providing such data, a direct inclusion of these values would be possible to allow a more complete life cycle scope. However, conservative ways to consider this effect should be sought until more robust data representing various scenarios is available.

Conversely, the impact of refrigerant leakage in B1 is significant. Choosing a refrigerant of low GWP has a much greater climate change mitigation potential than optimizing the material efficiency of HVAC systems. To estimate a potential leakage during building use and at end of life, a simple calculation method can be applied, consisting of a fixed annualised leakage rate and a fixed system replacement and decommissioning leakage rate of the total initial charge of the refrigerant. This will encourage designers to prioritise systems of low-GWP refrigerants in their projects. For example, a rough annual leak rate of 5% for split systems and 2% for heat pumps can be used as a rule-of-thumb. For the EoL stage the recovery rates provided in different sources vary more. As the regulations regarding refrigerants are becoming tighter and controls of the equipment maintenance and of the gas recovery, recycle, or destruction at the equipment become more rigorous, a recovery rate representing good practice could be chosen (e.g. 97%).

Finally, the inclusion of B1 module also becomes relevant when it reports one part of the CO_2 balance associated with vegetation integrated into buildings, while the other part is reported either under A1-3 or C3-4 modules. In this case, exclusion of B1 could lead to false conclusions about the environmental benefits of vegetated building elements. It is important to assess the full life cycle of the different components of a vegetated surface to compare it to more conventional solutions, as there are components which can be heavy contributors to such a roof's carbon footprint – such as the production and transport of the substrate as well as the production of drainage, filter layers and root barriers which are usually made of plastic or the use of irrigation systems and fertilizers over their service life.

In the case of B1 being out of scope, the users of the data of vegetated roofs and facades will need to subtract the sequestration/decomposition effect from the A and C modules; this would only be possible in the case of +A2 EPDs where GWP_{fossil} and $GWP_{biogenic}$ are reported separately or when a description of the amount of CO_2 sequestered as well as CO_2 and CH_4 released are provided.

B2 module

B2 has normally a low relative importance, however, it can demonstrate the benefits of concepts such as low-maintenance houses. The inclusion of B2 can also incentivize manufacturers to provide such values in their EPDs. If such values are provided including additional scenarios to facilitate the adjustment to a particular project's conditions, the effort to document this module will be low. Contrary to carbon footprint, maintenance-intensive products may have a considerable effect on life cycle costs or other environmental and health-related indicators. Furthermore, regular cleaning and maintenance contributes to extend a building's life, and thus avoid unnecessary waste, repair and replacement associated with building deterioration. Alternatively, considering that in most cases (upper quartile) this type of B2 impacts do not exceed 0.23 kgCO2eq./m^2/year (which is close to the default value also proposed by RICS: 0.2 kgCO2eq./m^2/year), the development and provision of a default value to be used in the absence of more specific data would be beneficial from a cost and effort perspective.

The benefit of reallocating glass replacement in B2 instead of B4 is the consistency with DS/EN 17213:2020. This supports the transition from generic data to product-specific EPDs along the design process and towards handover, if B2 is included in the requirement. Examples of Danish EPDs with glass replacement in B2 already exist.

Alternatively, the current established method can be adjusted in such a way while still being in line with the standard: setting the same service life for the glass and the frame, e.g. in year 25. In this way, there is no separation of the glass from the frame, but the replacement of the entire window is part of B4. Which way is closer to today's real practice and easier to implement in the various tools needs further investigation.

C1 and C2 modules

Some countries choose to include C1 and C2 modules in their regulation initially with one or more default values per m^2 of building to support the need for completeness while avoiding costs for the industry. Another notable approach is also treating C1 emissions as a proportion of A5 activities. As C1/C2 involve far future activities, their uncertainty combined with their small relative importance indicate a low relevance for time-consuming reporting. Ideally, the future grid decarbonization should be considered in the generation of default values.

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ANNEX A. NEW EMISSION FACTORS FOR OPERATIONAL ENERGY (B6)

Emission factors have been developed by Artelia A/S and are used in this report as data for sources of energy supply. They have been prepared on the basis of the Danish Energy Agency's analysis assumptions 2022. **Table 23** displays the values for every 5 years.

TABLE 23. Overview of emission factors for electricity, district heating and piped gas prepared by Artelia on the basis of the Danish Energy Agency's Analysis Assumptions 2022 (Sørensen, Høibye, & Enersen Maagaard, 2023).

kg CO2eq/kWh	***2025***	***2030***	***2035***	***2040***	***2045***	***2050***	***2055***	***2060***	***2065***	***2070***	***2075***
Electricity	0.0801	0.0325	0.0291	0.0285	0.0261	0.0248	0.0248	0.0248	0.0248	0.0248	0.0248
District heating	0.0418	0.0181	0.0140	0.0134	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132
Piped gas	0.1510	0.0557	0.0554	0.0554	0.0552	0.0551	0.0551	0.0551	0.0551	0.0551	0.0551

ANNEX B. REFERENCE VALUES FOR A4

TABLE 24. Background data for the national reference values for A4 for product groups provided in the BUILD report 2023:14 (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023).

Group	Subgroup	A4 in kgCO_2-eq per kg product	Truck distance	Ship distance
Concrete	Ready-mix	0.0019	25	0
Concrete	Wall / floor slab elements	0.0088	121	0
Concrete	Other precast elements	0.0171	233	0
Timber	Bars	0.0059	90	0
Timber	Boards (particle, OSB, plywood), planks, flooring	0.0393	500	392
Timber	Elements	0.0651	901	0
Steel	Reinforcement bars, nets, prestress wires	0.0073	100	0
Steel	Steel sheets and profiles	0.0099	350	0
Aluminium	Aluminium sheets and profiles	0.0069	800	0
Gypsum	Boards	0.0133	179	1500
Gypsum	Gypsum mortar and render	0.0167	450	0
Tiles and bricks	Brick	0.0036	50	0
Tile stone	Roof tiles	0.0072	100	0
Cementitious products	Aereated concrete blocks	0.0561	625	0
Cementitious products	Lightweight concrete blocks	0.0033	75	0
Cementitious products	Fibre cement boards	0.1609	1000	0
Cementitious products	Cementitious mortar and render	0.0840	682	0
Calcium-silicate	Sand-lime stone	0.0148	350	650
Zinc	Zinc sheets	0.0556	620	0
Bituminous products	Roofing felt	0.0302	697	0

Group	Subgroup	A4 in $kgCO_2$-eq per kg product	Truck distance	Ship distance
Openings	Windows	0.0677	755	0
Openings	Curtain wall facades	0.0152	170	0
Stone	Natural stone	0.0491	264	2825
Insulation	EPS	0.0487	167	0
Insulation	CalSil	0.0023	1239	0
Insulation	Cellulose	0.0577	299	0
Insulation	Wood fiber	0.0736	821	17
Insulation	Mineral wool	0.0157	312	0
Membranes and coatings	Vapor barrier	0.7500	1560	0
Membranes and coatings	Paint	0.0638	735	0
Services	Photovoltaic panels	0.2368	700	7305
Services	Ventilation components	0.0449	500	0
Services	Heating components	0.0449	500	0
Services	Mechanical components	0.0449	500	0
Services	Water and sewage system components	0.0449	500	0

ANNEX C. TIME INVESTMENT FOR REPORTING B1, B2, C1, C2

TABLE 25 Time investment needed to document B1, B2, C1, C2 for a standard single-family house building (150 m^2) in the year 5 (2027) assuming that a well-established routine in working with the requirement will already be in place after the first two years of its introduction.

Module	Aspect	Hours
B1	Carbonation	0.3
	Refrigerant leakage during use	~ 0
	(Net) carbon sequestration of vegetated surfaces	~ 0
B2	Maintenance of surfaces	0.3
	Replacement of filters	~ 0
	Replacement of glass	~ 0
C1	Deconstruction	~ 0
	Refrigerant loss	~ 0
C2	Transport	~ 0
Sum		0.6

Analysis of new modules in connection with calculation of the climate impact of buildings

Currently, the lifecycle scope included in the building regulation covers the product stage (A1-3), the replacements (B4) and parts of the end-of-life stage (C3-4) of buildings. The Danish Social And Housing Authority has asked BUILD to investigate the climate consequences of, and possibilities for including new stages and modules in the future requirement for climate impact of buildings. In this report, this has been seen in relation to the expected climate effect, availability of data and workload associated with the calculation of the modules that have been omitted in the 2023 requirement.