Bio-based building products in the Dutch Environmental Database (NMD)

Part 3: Example calculations on the environmental impact of A) building products and B) reference buildings to show the effects of: 1) bio-based vs. conventional building products, 2) crediting biogenic carbon storage

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Samenvatting

Het milieu-impactvoordeel van bio-based bouwproducten zit vaak verborgen in een breed scala aan levenscyclusanalyse (LCA)-gegevens die, hoewel ze allemaal gebaseerd zijn op dezelfde Europese norm (EN 15804), niet eenvoudig te vergelijken zijn. Deze complexiteit heeft te maken met verschillende databaseversies voor achtergrondgegevens die worden gebruikt om LCA's op te stellen, en met het feit dat milieuproductverklaringen (EPD's) worden opgesteld voor een product met specificaties (afmetingen e.d.) zoals de fabrikant verkiest. Dit betekent vaak dat de gegevens die in EPD's worden gepresenteerd, niet rechtstreeks kunnen worden vergeleken. Aan de andere kant wordt eenvoudig te begrijpen communicatie over de voordelen van bouwproducten vaak gedaan op 'marketingniveau', met minimale of selectieve onderbouwing van gegevens, of zonder alle details bekend te maken. Verder zijn de rekentools om de materiaalgerelateerde milieu-impact van gebouwen op een uniforme en verifieerbare manier te berekenen volgens de 'Bepalingsmethode' zoals die in Nederland wordt gebruikt, niet vrij beschikbaar; er is een licentie vereist. Wat ontbreekt, is een openbare, gedetailleerde, duidelijke en transparante rekentool voor de vergelijking van de milieu-impact van bio-based versus conventionele bouwproducten.

Verder ontbreekt een belangrijk voordeel van het gebruik van bio-based bouwproducten in de huidige Bepalingsmethode: de waarde van langdurige biogene koolstofopslag, die overeenkomt met een langdurige negatieve CO_2-uitstoot. Een recente studie heeft aangetoond hoe dit voordeel van biogene koolstofopslag kan worden gewaardeerd. Om inzicht te krijgen in de effecten van deze waardering, is het interessant om deze effecten op verschillende niveaus van milieu-impact te bekijken: Klimaatverandering (in het Engels 'Global warming potential', GWP); Milieukostenindicator (MKI); en de MilieuPrestatie Gebouwen (MPG).

Het doel van deze studie is om aan de hand van gedetailleerde voorbeeldberekeningen:

- De milieueffecten van bio-based versus conventionele referentiegebouwen te vergelijken;
- De milieueffecten van bio-based bouwproducten te vergelijken met conventionele producten op basis van een gelijk functioneel prestatieniveau;
- De effecten te illustreren van het waarderen van biogene koolstofopslag op MPG en MKI.

Op basis van de bepalingsmethode is de MPG[1] van biobased <u>huizen</u> lager dan voor huizen op basis van conventionele producten (beton, kalkzandsteen): 18-29% voor huizen met houtskeletbouw (TFC) en 24-35% voor huizen met kruislaaghout (CLT). Andere belangrijke observaties zijn:

- De verschillen worden voornamelijk veroorzaakt door de vloeren, gevel en constructie; en hebben voornamelijk betrekking op de materiaalproductie en het bouwen van de huizen.
- Individuele bouwcomponenten kunnen de MPG aanzienlijk beïnvloeden, bijvoorbeeld door slechte milieu-impactgegevens van categorie 3,[2] en zo de volgorde van de totale MPG-waarden veranderen.
- Hoe lager de totale MPG, hoe hoger de relatieve impact van 'standaard'-elementen zoals installaties, loodgieterswerk, verkeersruimte en terrein. Voor de range aan gebouwen zoals in deze studie bekeken, varieert het aandeel van deze standaardelementen van 23% voor een halfvrijstaand huis op basis van beton tot 54% voor een appartementencomplex op basis van CLT.
- De impactcategorieën die het meest bijdragen aan de MPG zijn: klimaatverandering (GWP), humane toxiciteit en verzuring. Deze categorieën vormen samen 85-88% van de MPG voor alle 3 gebouwtypen en alle 4 productbases; waarbij opgemerkt dat het hier om <u>relatieve</u> bijdragen

[1] Op basis van de weegset A1; nadere uitleg over weegsets is gegeven in de Box 2 in de Introductie (hoofdstuk 1).

[2] Gegevens van categorie 1 worden vastgesteld voor individuele bouwproducten. Gegevens van categorie 2 zijn representatief voor producten van groepen fabrikanten en/of leveranciers. Zowel gegevens van categorie 1 als 2 zijn onafhankelijk geverifieerd volgens het verificatieprotocol dat wordt beheerd door de Stichting Nationale Milieudatabase (NMD).
Gegevens van categorie 3 zijn vastgesteld door de NMD op basis van openbare literatuur, maar deze gegevens zijn niet geverifieerd; bij gebruik van gegevens van categorie 3 wordt een toeslagfactor van 30% toegepast om eventuele onderschattingen te compenseren.

gaat en dat dit geen invloed heeft op het feit dat bio-based gebouwen een lagere totale MPG hebben dan de conventionele varianten.

Op het niveau van bouwproducten, waarbij rekening houdend met gelijke functionele prestaties, hebben sommige bio-based producten in hun EPD's een veel hoger gewicht aangegeven dan hun conventionele referenties. Dit heeft een negatieve invloed op hun milieu-impact op MKI-niveau. Andere bio-based producten scoren een lagere (=betere) MKI dan hun conventionele tegenhangers.

Tevens zijn voorbeeldberekeningen uitgevoerd om de effecten te analyseren van een verdere detaillering en uitbreiding van het aantal milieu-impactcategorieën (IC's), waarover de Nederlandse overheid naar verwachting in 2025 een besluit zal nemen. Deze nieuwe set IC's en hun milieukosten wordt 'set A2' genoemd. Over het algemeen resulteert deze nieuwe methode in een toename van de milieu-impactkosten voor zowel bio-based als conventionele producten. Dit is het resultaat van de toename van het aantal IC's van 11 naar 19, en een toename van de kosten voor klimaatverandering (CC) in de nieuwe weegset. Voor de selectie van producten die zijn bekeken in deze studie neemt de MKI voor bio-based producten minder toe dan voor de conventionele referenties; gevolg is dat sommige bio-based producten de kloof met conventionele producten verkleinen, en andere bio-based producten beter scoren dan conventionele producten.
De bijdrage aan de MKI van enkele impactcategorieën in de nieuwe methode, die niet verplicht zijn in de EU maar wel zijn opgenomen in Nederland, is voor 6 van de 7 bekeken bio-based producten groter dan voor hun conventionele referenties.

Het waarderen van biogene koolstofopslag in gebouwen verlaagt de GWP, CC en MKI van bio-based bouwproducten aanzienlijk, tot af en toe negatieve waarden. Zelfs op gebouwniveau, inclusief een aanzienlijk aandeel niet-biobased producten voor de HSB- en CLT-varianten, daalt de MPG tot 10% voor HSB en ongeveer 25% voor CLT-huizen, versus tot 2% voor de kalkzandsteen- en betonvarianten. De MPG volgens set A2 zal naar verwachting nog verder dalen wanneer biogene koolstofopslag wordt gewaardeerd, gezien de toegenomen weging voor klimaatverandering in de MKI/MPG.

Summary

The quantified advantage of bio-based building products is often hidden in a wide range of life cycle analysis (LCA) data which are, although all based upon the same European standard (EN 15804), complex to compare. This complexity relates to different database versions for background data used to establish LCAs, and to the fact that environmental product declarations (EPDs) are established for any product definition the manufacturer may choose, which often means that the data presented in EPDs cannot be compared directly. On the other hand, easy to understand communication on the advantages of building products is often done at 'marketing level', with minimal or selective underpinning of data, or without disclosing all details. Further, the tools to calculate the material-related environmental impact of buildings in a uniform and verifiable manner according to the 'Determination Method' as used in the Netherlands are not freely available; a license is required. What is missing is a public, detailed, clear and transparent tool for the comparison of the environmental impact of bio-based versus conventional building products.

Further, a key benefit of using bio-based building products is missing in the present Determination Method: The additional value of long term biogenic carbon storage, which corresponds to a negative CO_2 emission. A recent study has shown how this benefit of biogenic carbon storage can be credited, and for getting an insight in the effects of this credit, it is of interest to review these effects on different environmental impact levels: Global warming potential (GWP); Environmental cost indicator (in Dutch 'milieukosten indicator', MKI); and the Environmental impact of buildings (in Dutch 'Millieuprestatie gebouwen', MPG).

The objective of this study is to provide detailed example calculations to:

- Compare the environmental impacts of bio-based versus conventional reference buildings;
- Compare the environmental impact of bio-based building products versus conventional products at equal function performance level;
- Illustrate the effects of crediting biogenic carbon storage on MPG and MKI.

Based on the Determination Method, the MPG[3] of bio-based houses is lower than for houses based on conventional products (concrete, sand-lime): 18 – 29% for timber frame construction (TFC) houses, and 24-35% for cross laminated timber (CLT) based houses. Further key observations include:

- The differences are mainly caused by the floors, façade and construction; and mainly relating to the material production and construction of the buildings.
- Individual components can significantly affect the MPG, e.g. due to poor Category 3 environmental impact data,[4] and thus change the order of total MPG values.
- The lower the total MPG, the higher the relative impact of 'default' elements like installations, plumbing, circulation space and terrain. For the range of buildings considered in this study, the share of these default elements ranges from 23% for a concrete based semi-detached building to 54% for a CLT based apartment flat.
- The impact categories contributing most to the MPG comprise: Global warming potential (GWP), human toxicity potential (HTP) and acidification potential (AP), the total of which constitutes 85-88% of the MPG for all 3 building types and all 4 product bases. It may be noted that this refers to relative contributions and that this does not affect the fact that the bio-based buildings have a lower total MPG than conventional variants.

At building product level, considering equal functionality performance, some bio-based products have declared in their EPDs a much higher weight than their conventional references, which negatively affects

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[3] Using weighting set A1; see explanation on weighting sets in Box 2 in the Introduction (chapter 1).
[4] Category 1 data are established for individual building products. Category 2 data are representative for products from groups of manufacturers and/or suppliers. Both Cat 1 and 2 data have been verified independently in accordance with the Verification protocol managed by the Foundation National Environmental Database (NMD).
Category 3 data have been established by the NMD based on public literature, however, these data have not been verified; when using category 3 data, an uplift factor of 30% is applied to compensate eventual underestimations.

their environmental impact at MKI level. Other bio-based products score a lower (=better) MKI than their conventional counterparts.

Further example calculations were performed to analyse the effects of further detailing and expansion of the number of environmental impact categories (ICs) on the MKI and MPG, and for which the Dutch government is expected to take a decision in 2025. This new set of ICs and their environmental costs is called ‘set A2’. In general, this new method results in an increase of environmental impact costs for both bio-based and conventional products. This is the result of the increase in number of ICs from 11 to 19, and an increase of the costs for climate change (CC) in the weighting set. For the studied selection of products, the MKI for bio-based products increases less compared to the conventional references, ranking from scoring better than conventional products to partially decreasing the gap.
The contribution of a couple of impact categories in the new method, which are not obligatory in EU but included in the Netherlands, on MKI are larger for 6 out of 7 bio-based products than for their conventional references.

Crediting biogenic carbon storage in buildings largely reduces the GWP, CC and MKI of bio-based building products, down to occasionally negative values. Even at building level, including a significant share of non-biobased products for the TFC and CLT variants, the MPG decreases up to 10% for TFC and about 25% for CLT houses, versus up to 2% for sand-lime and concrete variants. The MPG according to set A2 is anticipated to reduce even more when biogenic carbon storage is credited, considering the increased weighting of the climate change impact category in the MKI/MPG.

1 Introduction

Need for transparent sustainability claims

The Dutch Government targets to reduce CO_2 emissions by 49% in 2030, and virtually net zero CO_2 emissions by 2050, in order to combat climate change. The building and construction sector can contribute significantly to this goal by applying bio-based and circular building products. The quantified advantage of bio-based building products, however, is often hidden in a wide range of life cycle analysis (LCA) data which are complex to compare. For instance, the existence of different database versions for background data to establish LCAs hinders a fair comparison of the output data of these LCAs. Also, environmental impact of products needs to be compared at equal performance level, while environmental product declarations (EPDs) are established for any product definition the manufacturer may choose, which often means that the data presented in EPDs cannot be compared directly.

In order to calculate the material-related environmental impact of buildings and civil engineering works over their entire life cycle in a uniform and verifiable manner, in the Netherlands, the 'Determination Method' (officially: The Environmental Performance of Buildings and civil engineering works Determination Method ('Determination Method' in short)[5] has been developed. This method is managed by the Dutch National Environmental Database foundation (in Dutch: 'Nationale Milieu Database', NMD). EPD data of building products are established based on LCA, according the framework specified in the Determination Method. After verification, these EPD data are entered in the NMD database. The Determination Method also specifies calculation rules for determining the material-related environmental impact of buildings. Tools to actually calculate the environmental impact, however, are only available to parties having a license, which poses a hurdle for free use.

Box 1. Life cycle assessment (LCA)

LCA comprises the quantification of a the environmental impacts of all stages of a product: Feedstock production, product manufacturing, building and construction processes, maintenance and repair during the use phase, building demolition, waste processing and disposal. The Determination Method also allows to credit benefits of avoiding virgin material production by recycling of materials after end-of-life, which is outside the standard LCA methodology.

Figure 1 presents an overview of the different aspects of life cycle phases A to D considered for building products.

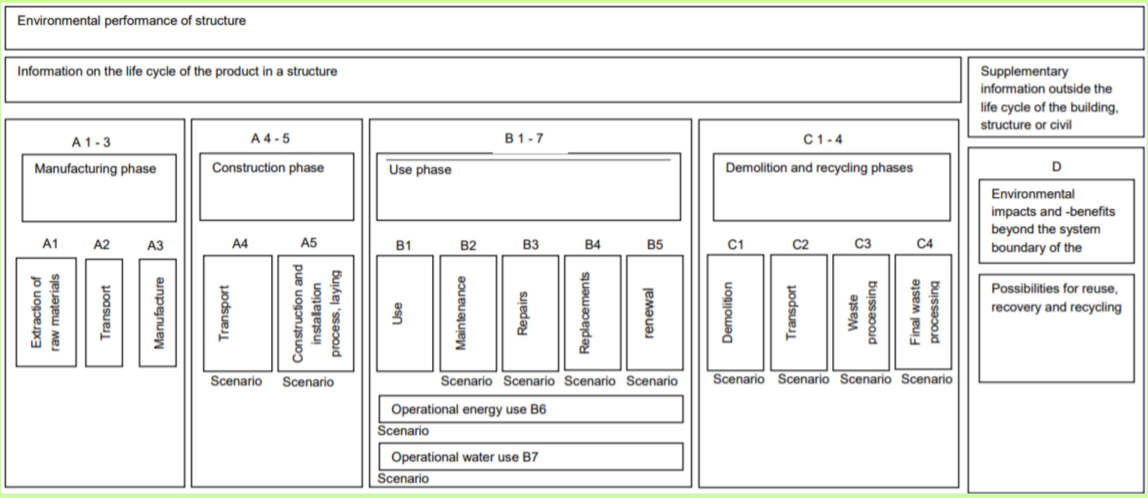

Figure 1 Life cycle phases in LCA and EPDs.

[5] In Dutch 'Bepalingsmethode Milieuprestatie Bouwwerken', 'Bepalingsmethode' in short.
https://milieudatabase.nl/media/filer_public/89/42/8942d5dd-8d37-4867-859a-0bbd6d9fb574/bepalingsmethode_milieuprestatie_bouwwerken_maart_2022_engels.pdf

Further, easy to understand communication on the advantages of bio-based building products is often done at 'marketing level', mentioning benefits for environmental impact categories for which the specific building products scores comparatively well, with minimal underpinning of data, or without disclosing all details. Also, some studies report that specific conventional products still outperform bio-based products regarding environmental impact. In short: What is missing is a public, detailed, clear and transparent comparison of the environmental impact performance at the level of the several individual impact categories (IC), the environmental cost indicator of building products (in Dutch: 'Milieukosten indicator', MKI), and the environmental impact of buildings (in Dutch 'Milieu Prestatie Gebouwen', MPG) of bio-based versus conventional building products.

Box 2. Environmental cost indicators

The production of building products comes with different environmental impacts such as global warming potential (GWP), toxicity for humans, acidification, etc. These impacts are quantified using LCA according to EN 15804. In the Netherlands, the environmental impacts of building products are monetized by attributing euro costs (also called 'weighting factor') to each of these impact categories, in order to allow the translation of the different environmental impacts in a single number for more simple comparison. So far, EN version 15804+A1 has been used, with corresponding weighting factors, called 'set A1'. The environmental cost indicator of building products according to this method is called 'MKI-1', and comprises 11 environmental impact categories.

In 2025, the Dutch government is expected to take a decision on implementation of the update EN 15804+A2. This updated method comprises some modifications regarding impact categories, and with corresponding weighting factors, called 'set A2'. The environmental cost indicator of building products according to this method is called 'MKI-2', and comprises 19 environmental impact categories.

The environmental impact of an entire house (MPG) is calculated as the sum of the MKIs for all building products applied. The MPG is calculated per m^2 gross floor surface and per annum of service

Additional value of biogenic carbon storage

One of the advantages of bio-based building products includes long term storage of CO_2 which recently has been absorbed from the atmosphere, and which corresponds to a negative CO_2 emission. This benefit, however, is not credited in the present Determination Method. A recent study has shown how this benefit of biogenic carbon storage can be credited.[6] It is of interest to review the effect of this credit on different environmental impact levels: Global warming potential (GWP), MKI, MPG.

Objective of this study

This TKI Agri & Food funded study[7] aims to provide detailed example calculations to:

- Compare the environmental impacts of bio-based versus conventional reference buildings at the level of building (MPG), building elements and impact categories (chapter 2);
- Compare the environmental impact (IC, MKI) of a couple of bio-based building products versus conventional products at equal function performance level, at the level of MKI-1, MKI-2, GWP and climate change (chapter 3);
- Illustrate the effects of crediting biogenic carbon storage (chapter 4).

[6] WUR, 'Bio-based building products in the Dutch Environmental Database (NMD) - Part 1: Proposal for crediting biogenic carbon storage' (2024), https://edepot.wur.nl/647711

[7] https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/food-biobased-research/show-fbr/milieu-prestatie-biobased-bouwmaterialen-in-de-nationale-milieudatabase.htm

2 Environmental impact of bio-based versus conventional houses

Bio-based building products are promoted by a couple of claims, one of which being a lower environmental impact compared to products made from conventional building products. In this chapter, the environmental impact is analysed <u>on building level</u> by performing MPG example calculations for conventional reference houses versus bio-based 'equivalents' according to weighting set A1. This is done for 3 types of houses (terraced house, semi-detached house, apartment flat M)[8] and 4 variations of construction products/methods per type of house (Concrete; Sand-lime brick; Timber frame construction (TFC); Cross laminated timber (CLT)). These example calculations have been based as much as possible on so called Category 2 product cards, which are representative for products from groups of manufacturers/suppliers (section 2.1; Annex 3).
In chapter 3, a comparison is made on <u>building product level</u>, i.e., the environmental impact of a selection of bio-based building products is compared to conventional products for equal performance in selected applications. These example calculations have been based on so called Category 1 product cards, which are established for products of individual manufacturers (section 3.1 & 3.2; Annex 5).

2.1 Methodology

In following sections the environmental impact of buildings (MPG) is compared for bio-based versus conventional reference houses. The approach comprises the following steps:

- Definition of 3 types of reference houses (terraced house, semi-detached house, apartment flat M) is copied from BENG[9] reference buildings.[10,11]
    - The materialisation of these reference houses has been described in Annex 1.
    - A few low-impact products which are equal for all 5 types of construction have been omitted (details see Annex 1).
- Per type of house, 4 variations have been specified based on: Concrete; Sand-lime brick; Timber frame construction (TFC); Cross laminated timber (CLT).
    - Building product selection is based on available EPD data in the Dutch NMD database and in GPR-Gebouw software.
    - Cross sections and thicknesses for constructive and finishing products for TFC and CLT variations have been detailed according to NBVT guidelines,[12] and INBO guidelines.[13]
    - Insulation thickness has been adapted to Rc values of 4.7, 6.3 and 3.7 for façade, roof and floor, respectively. Also, regulations for fire and acoustics requirements have been addressed.
    - A couple of elements have been kept constant for all 4 variations per type of building:
        - Climate installations; Electrical installations; plumbing; circulation space; Terrain
    - Occasionally, building products are available in the NMD database for 1 application, while not for another application; e.g. OSB and gypsum board. In such cases, the

[8] Translation to Dutch: terraced house = rijtjeshuis; semi-detached house = 2 onder 1-kap huis; apartment flat M = flatgebouw met 6 bouwlagen en 31 appartmenten.
[9] Nearly Energy Neutral Buildings; in Dutch 'Bijna EnergieNeutrale Gebouwen', BENG.
[10] DGMR, 'Referentie gebouwen BENG' (in Dutch), 2017, https://www.rvo.nl/sites/default/files/2017/02/Referentiegebouwen%20BENG.pdf
[11] W/E Adviseurs, 'Materialisatie referentiebouwwerken - Uitbreiding toepassing BENG-referentiegebouwen & toevoeging GWW-referentie ten behoeve van set referentiegebouwen voor monitoring- en effectstudies Milieuprestatie (in Dutch), 2019, https://milieudatabase.nl/media/filer_public/f3/0f/f30f1614-eea4-4ee1-8dcf-3455aba977a7/we9799-eindrapport-materialisatie-referentiegebouwen_22-juli-2019.pdf
[12] NBVT, 'Invoerinstructie NBVT houtskeletbouw elementen voor MPG-makers' (in Dutch), 2023 https://nbvt.nl/downloads/mpg-invoerinstructie-houtskeletbouw/
[13] INBO, CLT Handleiding (in Dutch), 2021, https://inbo.com/wp-content/uploads/2022/12/CLT-Handleiding-voor-architecten-en-bouwkundigen.pdf

        - available products have been selected as well for the applications for which no specific product is available, considering respective amounts (m^2 and thickness).
    - The details of the building products have been described in Tables A2.1 – A2.3 in Annex 2.
    - A couple of low-impact products for which no bio-based alternatives are available today and which are equal for all 4 types of construction have not been included in the calculations: Finishes, bathroom, window sills, solid screens and rainscreens.
- Comparison is made using calculation tool 'GPR Materiaal'.
    - Modules A to D have been included, as required in the Netherlands.
    - If available in the NMD database, so called environmental impact 'category 2 data' representative for products from groups of manufacturers and/or suppliers and sectors have been used.[14] These data have been verified by an independent, qualified third party in accordance with the NMD Verification protocol.
    - If no products with category 2 data were available in the NMD database, then category 3 data have been used. These data have been established by Stichting National Environmental Database based on public literature, however, these data have not been verified according to the Verification protocol. When using category 3 data, an uplift factor of 30% is applied to compensate eventual underestimations.[14]
    - Occasionally, if no category 2 nor 3 data were available, category 1 data have been used. These data are based on proprietary data from manufacturers and suppliers for individual building products. Like category 2 data, these data have been verified by an independent, qualified third party in accordance with the NMD Verification protocol. However, data of such individual products may be less representative for the broad range of building products available for the purpose.
    - Generally, the same category level of EPD data could be selected for the different types of construction, with a few exceptions. Main exception comprises: Pressure layer of storey floors (3a in Annex 3), as well as pressure layer of apartment roofing construction (7a) which are category 3 for the concrete and sand-lime types, versus category 2 for the TFC types and category 1 for the CLT types. Further, category 1 data had to be selected for CLT story floors (3a), roof construction (7a) and built-in non-load bearing system (8b); for CLT and sand-lime load bearing separation walls (4a) and façade cavity walls (5b); and for concrete and sand-lime built-in non-load bearing solid (8f). An overview of the category level of EPD data selected for the MPG example calculations is presented in Annex 3.
    - The export dataset has been 'frozen' on 15th March 2024.

2.2 Results

The MPG value per life cycle phase according to weighting set A1 for 4 different variations of construction products/methods for terraced houses, semi-detached houses and apartment flats has been presented in Figure 2. These MPG values include modules A to D, as required in the Netherlands. Numerical data have been listed in Annex 4. Observations and discussion:

- Bio-based houses (TFC, CLT) exhibit lower MPG than houses based on conventional products (concrete, sand-lime).
- This difference is mainly due to the material production and construction of the buildings (phase A).
- Comparing CLT and TFC, the higher benefit in module D for CLT compensated by its higher impact in modules A to C, thus leading to a lower MPG value for CLT compared to TFC.
- The relatively higher impact during the use phase (phase B) for TFC is mainly due to the use of OSB panels having a reported service life of 25 years, thus leading to an additional impact in phase B of twice the total impact of the OSB panels. In practice, however, the service life of the OSB panels may be expected to be the service life of the building, thus not leading to the additional impact in phase B.

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[14] https://milieudatabase.nl/en/database/dutch-environmental-database/

- Moreover, OSB panels in the NMD database are Cat. 3 product cards, which impact data happen to be significantly higher than for state-of-the-art OSB panels.
- The higher impact for the inner walls and roofs for TFC terraced and semi-detached houses compared to CLT houses is due to the Cat. 3 OSB panel data used for TFC variants; the Cat. 3 OSB panel impact data in the NMD database happen to be significantly higher than for state-of-the-art OSB panels. The total impact of the OSB panels in the TFC terraced and semi-detached houses, 0.036 and 0.033 respectively, is larger than the difference between the total MPG of the TFC and CLT houses, 0.027 and 0.025 for terraced and semi-detached houses, respectively.
- The small impact in the demolition and waste processing phase (phase C) for the TFC house is due to a lighter crane which can be used for demolition, as well as lower transportation load.

  It may be noted that the initial impact result was even lower, and urged to review the results in more detail. Both GWP and ADP Fossil Energy appear to contribute a negative value to the overall MKI for phase C of the TFC house, especially GWP. In Figure 2, the following (small) corrections have been included. Considering that for the CLT house the contribution of GWP in the total MKI for phase C is 45%, 45% and 42% for terraced, semi-detached and apartment houses, respectively, (45-54% for sand-lime and concrete houses) and that the contribution of ADP Fossil Energy is 0.4% (0.2-0.5% for sand-lime and concrete houses), the values for the TFC house have been modified to obtain the same percentage contribution of GWP and ADP Fossil Energy in the total MKI.
- The defined TFC houses still contain conventional glass wool insulation, concrete roofing tiles and brick outer façade. A 'fully' bio-based variant including wood fibre insulation, reed roofing and treated wood based façade cladding showed overall negative values for phase C. Detailed review of the data, which were all based on EPD data stored in the NMD database, clarified that 6 out of 11 impact categories contributed a negative value to the MKI for phase C. Therefore, this variant has been excluded from the results, however, considering the trend of decreasing impact when using bio-based building products, it may be expected that increased use of bio-based building products will lead to further reduction of environmental impact.

The contribution of the different building elements to the MPG for 4 different variations of construction products/methods for terraced houses, semi-detached houses and apartment flats is presented in Figure 3. Numerical data have been listed in Annex 4. Observations and discussion:

- Apart from the installations and other elements which have been selected identical for all 4 variations, the floors and façade walls contribute the most to the impact.
- The difference between bio-based (TFC, CLT) and conventional houses (concrete, sand-lime) is mainly caused by the floors, façade and construction.
- The lower the total MPG, the higher the relative share of 'fixed' elements like electrical and climate installations, plumbing, circulation space and terrain. In total, this fixed share ranges from 23% to 34% for concrete to CLT based semi-detached buildings, respectively, and from 34% to 52% for concrete to CLT apartment flats, respectively.
  - It may be investigated to which extent 'lighter' climate installations for TFC and CLT variants can be allowed, without compromising necessary technical and health requirements. This because current building regulations (NTA 8800) are mainly designed for traditional building methods and TFC and/or CLT buildings sometimes are forced to install too heavy installations only to meet the requirements set out.
- Generally, the same category level of EPD data could be selected for the different types of construction. The key exception is the pressure layer of storey floors of the concrete and sand-lime variants which is based on Cat. 3 data for which a 30% uplift is applied. This uplift corresponds to a contribution in the MPG of 0.0145, 0.013 and 0.018 for the terraced, semi-detached and apartment houses, respectively, which is about 10% of the total MPG of the floors.
- The second exception is the pressure layer of the apartment roofing construction for the concrete and sand-lime types being based on Cat. 3 data. The 30% uplift corresponds to a contribution of 0.004 in the MPG of the concrete and sand-lime apartment houses. The total of these 2 uplifts is about 2.7% for terraced houses, 2.3% for semi-detached houses and 3.0% for apartment houses.
  - It may be noted that the value for the terraced house is larger than for the semi-detached house. This relates to the fact that the total sum of MKIs is calculated per

gross floor surface. Since the ratio of gross floor surface over storey floor surface is higher for the semi-detached house compared to the terraced house, the MPG value for the semi-detached house will be lower.

- The higher impact for the inner walls and roofs for TFC terraced and semi-detached houses compared to CLT houses is due to the Cat. 3 OSB panel data used for TFC variants; the Cat. 3 OSB panel impact data in the NMD database happen to be significantly higher than for state-of-the-art OSB panels. The total impact of the OSB panels in the TFC terraced and semi-detached houses, 0.036 and 0.033 respectively, is larger than the difference between the total MPG of the TFC and CLT houses, 0.027 and 0.025 for terraced and semi-detached houses, respectively.

The relative contribution of the different environmental impact categories to the MPG of 4 different variations of construction products/methods for terraced houses, semi-detached houses and apartment flats is presented in Figure 4. It may be noted that the total MPG impact for the different variations differs as presented in figures 2 and 3. Numerical data have been listed in Annex 4. Observations:

- Global warming potential (GWP) constitutes the largest impact to the MPG, followed by human toxicity potential (HTP)[15] and acidification potential (AP). Total share of these 3 ICs is 85-88%.
- The share of GWP in the respective totals is a bit higher for conventional building variants compared to bio-based variants (TFC, CLT), whereas for HTP and AP it is the other way round.

[15] It may be noted that human toxicity for bio-based building materials is mainly determined by background processes in factories for sub-components such as e.g. the production process of glues, and does not lead to human toxicity in buildings.

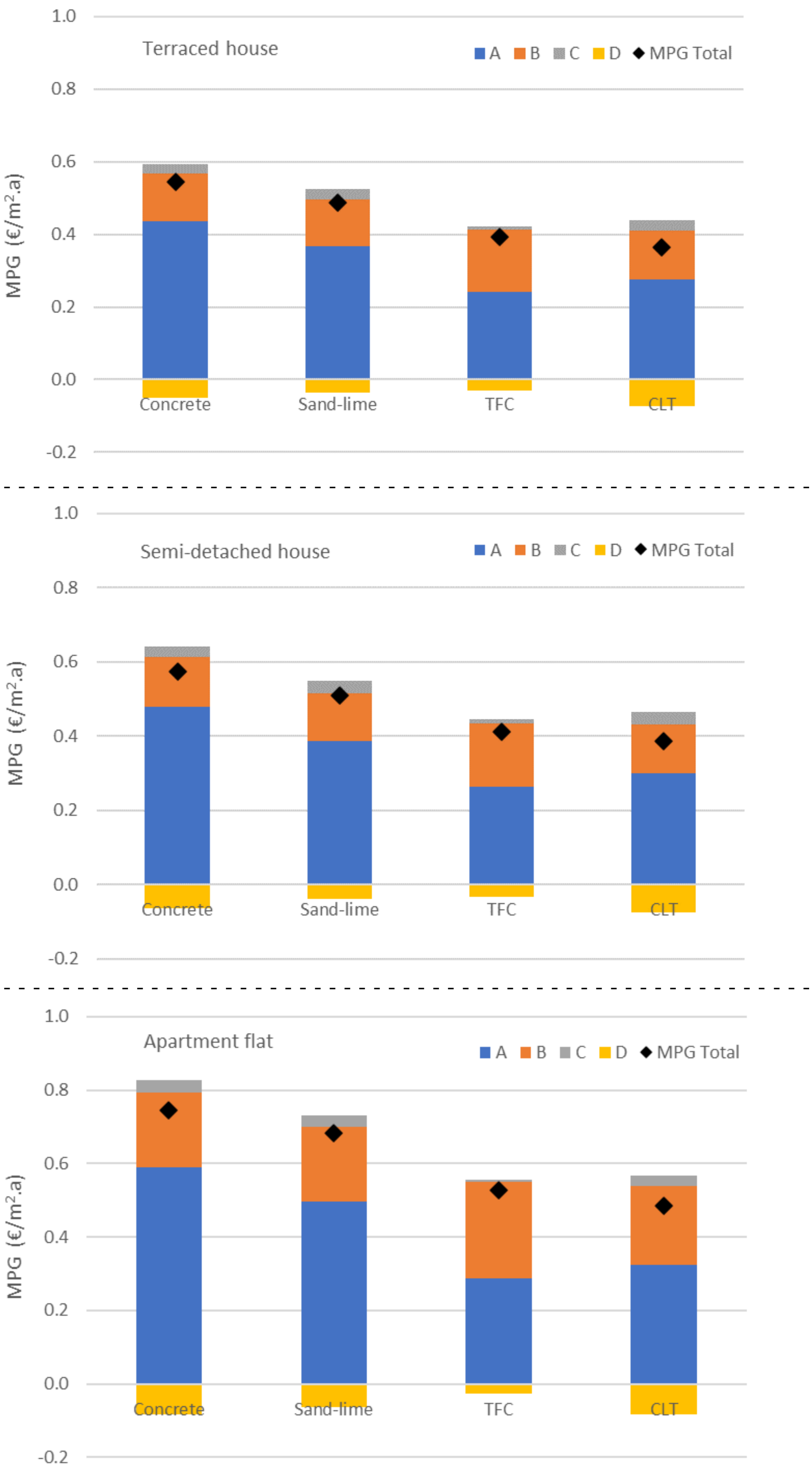

Figure 2 ***MPG of 4 different variations of construction products/methods for terraced houses (top), semi-detached houses (middle) and apartment flats (bottom), according to set A1. Numerical data are presented in Annex 4. For explanation of phases A – D, see box 1 in the Introduction.***

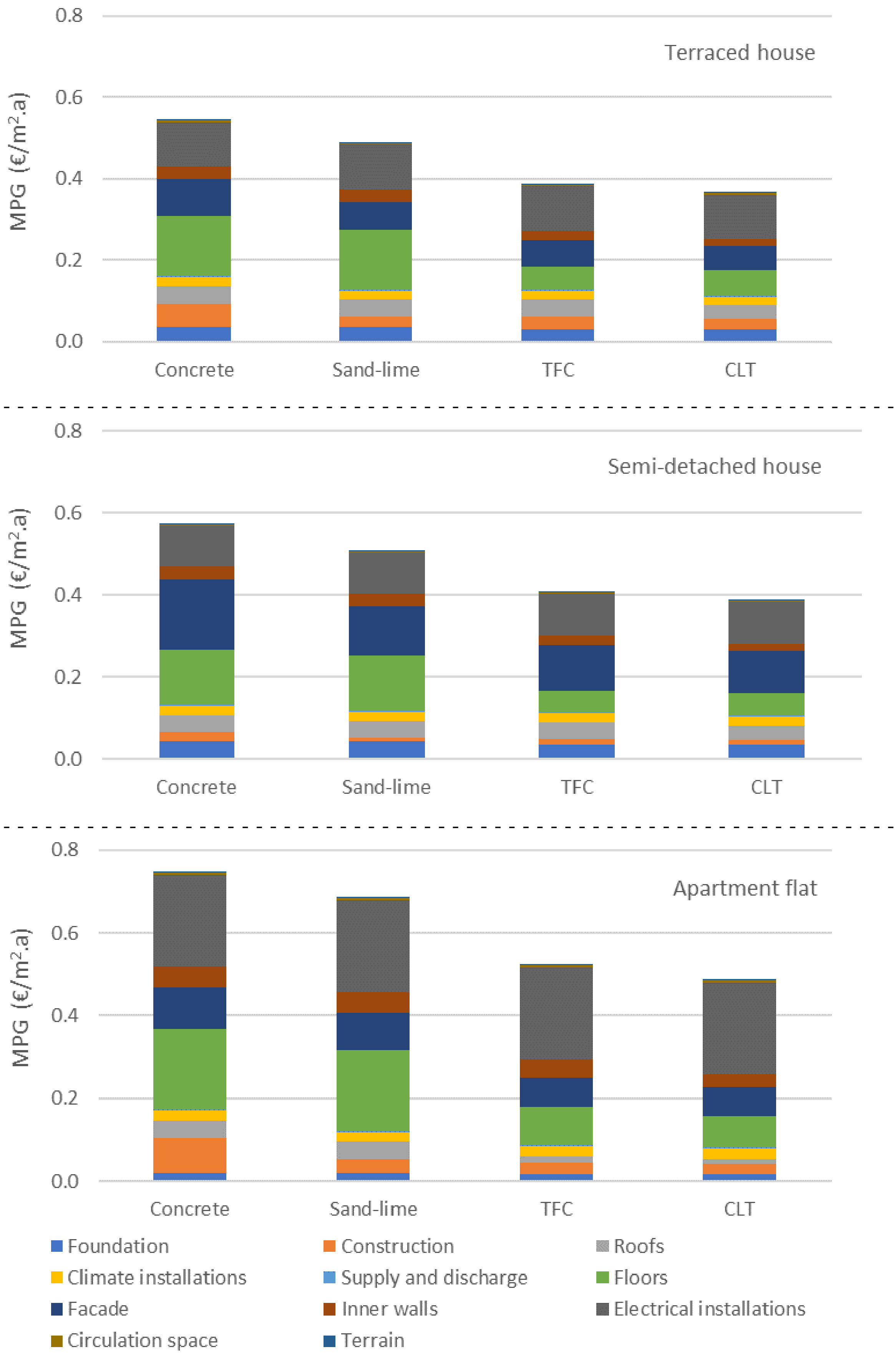

Figure 3 ***Contribution of building elements to MPG of 4 different variations of construction products/methods for terraced houses (top), semi-detached houses (middle) and apartment flats (bottom), according to set A1. Numerical data are presented in Annex 4.***

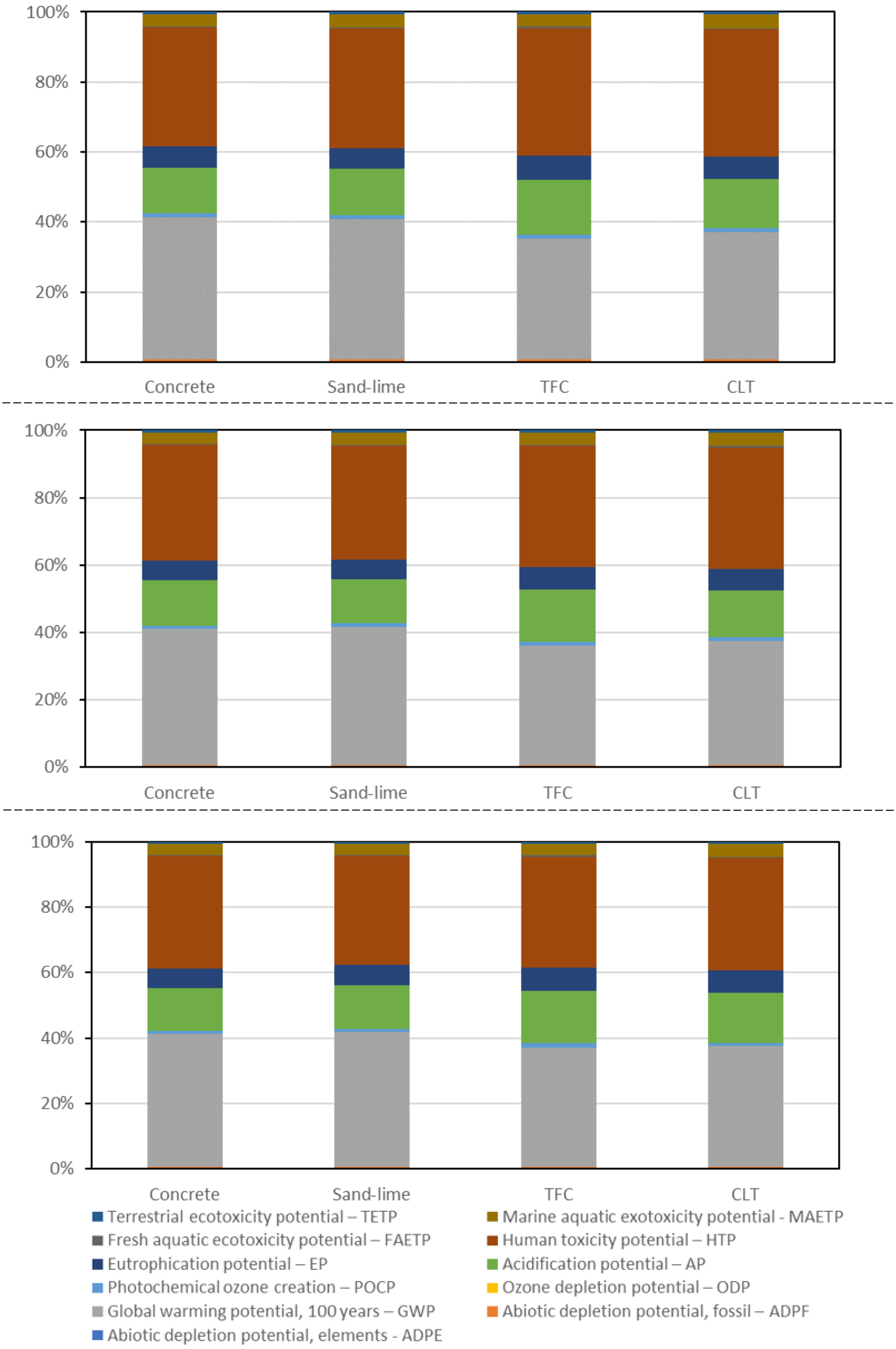

Figure 4 ***Contribution of environmental impact categories to MPG of 4 different variations of construction products/methods for terraced houses (top), semi-detached houses (middle) and apartment flats (bottom), according to set A1. Note that total impact differs (see Figure 2).***

2.3 Conclusions

- Bio-based houses (TFC, CLT) exhibit lower MPG than houses based on conventional products (concrete, sand-lime) (Figure 2):
    - Terraced house: TFC gives 19 and 27% lower MPG impact compared to sand-lime and concrete, respectively; CLT gives 25 and 33% lower impact;
    - Semi-detached house: TFC gives 18 and 27% lower MPG impact compared to sand-lime and concrete, respectively; CLT gives 24 and 33% lower impact;
    - Apartment flat: TFC gives 23 and 29% lower MPG impact compared to sand-lime and concrete, respectively; CLT gives 29 and 35% lower impact.
- The differences are mainly caused by the floors, façade and construction; and mainly relating to the material production and construction of the buildings (phase A).
- Individual components can significantly affect the MPG, e.g. due to poor Cat. 3 data, and thus change the order of total MPG values.
- The lower the total MPG, the higher the relative share of 'fixed' elements like installations, plumbing, circulation space and terrain. For the range of buildings considered in this study, the share of these fixed components range from 23% for the concrete based semi-detached building to 54% for the CLT based apartment flat.
- The impact categories contributing most to the MPG comprise: Global warming potential (GWP), human toxicity potential (HTP) and acidification potential (AP), the total of which constituting 85-88% of the MPG for all 3 building types and all 4 product bases.
    - Please note that this refers to <u>relative</u> contributions and that this does not affect the fact that bio-based building have a lower <u>total</u> MPG than conventional variants.
- The share of GWP in the respective totals is a bit higher for conventional building variants compared to bio-based variants (TFC, CLT), whereas for HTP and AP it is the other way round.

3 Environmental impact of bio-based versus conventional building products

Bio-based building products are promoted by a couple of claims, one of which being a lower environmental impact compared to conventional building products. In this chapter, the environmental impact of a couple of bio-based building products is compared to conventional products for equal key performance in selected applications. The product groups include: Rigid insulation boards; flexible insulation mats; crawl space insulation; building blocks for inner walls. Single product applications have been selected in order to avoid complex calculations and correspondingly complex conclusions.
In the following sections, the methodology (§3.1), product data required in the comparison (§3.2) and results (§0) have been presented. The comparison is based on EPDs, corresponding to Category 1 product card level, which are established for products of individual manufacturers.

3.1 Methodology

The approach comprises the following steps:

- Collecting EPDs which are still valid at the moment of writing, and based on the same database version: EcoInvent v3.6.
    - For bio-based products, EPDs have been established in this project.[7]
    - For conventional references, EPDs have been sourced online (Annex 5). It may be noted that the status of these EPDs is not exactly clear, however, the 'valid to' dates on the EPDs indicates that a review has taken place.
- Copying the environmental impact data into Excel.
- Calculate the 'multiplication factors' for each product to allow comparing per group of products at equal performance on key function level. The subsequent steps include:
    - Compare the performance characteristics per functional unit as specified in the EPD versus the target function level (e.g. Rd = 4.7).
    - Determine the multiplication factor required to translate the product performance per functional unit into the target function performance.
    - Service life of all products is considered 75 years.
- Multiply the environmental impact data from the product's EPD by this multiplication factor to obtain the impact of that product at target function performance.
- Comparison is made for the impact categories GWP and climate change.
    - Comparisons can be made as far as data for the different impact categories are included in the EPDs. Since up-to-date public EPDs are relatively scarce, EPDs for reference of conventional building products have been sourced outside the Netherlands as well. At the same time, the Netherlands consider 11 ICs in set A1 whereas most other European countries consider 7 of these ICs only. Also for set A2, not all EPDs present data for all 19 ICs considered in the Netherlands.[16] As a consequence, comparisons have been made as far as data are available. Availability of data will be addressed while presenting the results in section 0.
- Environmental cost indicator (in Dutch: 'milieukosten indicator', MKI) values are calculated according to the weighting sets of EN 15804+A1 and A2.
    - For set A2 impact categories, the foreseen monetary weighting factors are used.[17]
    - The weighting factors for set A1 and set A2 impact categories are presented in Annex 6 and Annex 7, respectively.
    - The MKI values are coded 'MKI-1' for set A1 impact categories, and 'MKI-2' for set A2.

[16] The impact categories (ICs) are numbered: 001 – 014 for set A1, and 051 – 069 for set A2 (details see Annex 6 and 7). In most European countries, IC 001 – 008 are considered for set A1, and 051 – 063 for set A2, whereas the Netherlands consider all 11 and 19 ICs.
[17] https://open.overheid.nl/documenten/b376fac3-a074-4bac-9ad0-3c10588d465b/file

3.2 Comparison at equal performance on function level

The key performance characteristic of the reviewed bio-based and conventional rigid insulation boards as presented in the EPDs are presented in Table 1 – Table 4. Also, the multiplication factors required to obtain equal performance at key function level are included. The function level is indicated in the heading of each table.

Table 1 Characteristics of rigid insulation board to meet Rd = 4.7.

Product	λ (W/m.K)	Density (kg/m³)	Thickness, d, in EPD (m)	Rd at d (m².K/W)	Multiplication Factor
Gutex Ultratherm	0.040	167.1	0.14	3.50	1.343
Gutex Thermoroom	0.040	165.5	0.14	3.50	1.343
Pro Suber ICB	0.039	115	0.14	3.60	1.306
Bewi EPS	0.038	15	0.038	1.00	4.700
Bewi XPS	0.034	31.5	0.034	1.00	4.700

Table 2 Characteristics of flexible insulation mats to meet Rd = 4.7.

Product	λ (W/m.K)	Density (kg/m³)	Thickness, d, in EPD (m)	Rd at d (m².K/W)	Multiplication Factor
Isolena Optimal	0.036	50	0.12	3.3	1.424
Gutex Thermoflex	0.0385	18	0.135	3.5	1.343
URSA Glasswool	0.032	76.5	0.025	0.78	6.026
ODE Glasswool	0.04	12	0.04	1.00	4.700

Table 3. Characteristics of crawl space insulation to meet Rd = 3.7.

Product	λ (W/m.K)	Density (kg/m³)	Thickness, d, in EPD (m)	Rd at d (m².K/W)	Multiplication Factor
Isoschelp	0.1305	650	0.3	2.299	1.610
EPS chips *	0.068	5.39			2.379
Argex	0.114	340	0.114	1	3.700

* Data for EPS chips based on Bewi EPS (Table 1). Lambda value derived from Drowa insulation chips, Rd=14.7 at a thickness of 1 m.[18] Density determined in own lab at WFBR.

Table 4. Characteristics of building blocks for inner walls at 10 cm thickness.

Product	λ (W/m.K)	Density (kg/m³)	Thickness, d, in EPD (m)	Rd at d (m².K/W)	Multiplication Factor
Isohemp *	0.071	351	0.36	5.07	0.278
Bauroc AAC *	0.080	388	1	12.50	0.100

* Similar layers of stucco, required to achieve the sound reduction, are not included.

[18] https://www.drowa.nl/rd-en-rbf-waardes-van-drowa-isolatiechips/, accessed 28 May 2024.

3.3 Results & discussion

3.3.1 Pressure-resistant insulation boards

Figure 5 and Figure 6 present the MKI-1 and MKI-2 data per life cycle phase A – D for pressure-resistant insulation boards. For explanation of the life cycle phases, and MKI-1 and MKI-2, see the Boxes 1 and 2 in the Introduction, respectively.

The relatively high weight of the bio-based products required to deliver an Rd of 4.7 largely affects MKI, the weight per m^2 being 31.4, 31.1 and 21.1 kg/m^2 for bio-based versus 5.0 and 2.7 kg/m^2 for the conventional reference, respectively. Considering the weights, the bio-based products score relatively well compared to XPS/EPS, however, XPS/EPS require far less weight to deliver the same insulation performance. The Pro Suber cork insulation product performs best for both MKI-1 and MKI-2, whereas the wood fibre products come more close to the XPS references when going from MKI-1 to MKI-2.

Next to providing thermal insulation in winter, the wood fibre and cork based boards provide another advantage: Wood fibre and cork board insulation provide much better heat insulation during summer as well as better sound insulation.

The relative increase of MKI-2 versus MKI-1 for the bio-based products is 1.5 – 2.0, including all 11 ICs for MKI-1. This is due to the number of ICs increasing from 11 to 19, and increase of attributed costs for impact on Climate Change in MKI-2 relative to GWP in MKI-1. For the XPS and EPS products, the relative increase is 3 and 15, respectively, excluding ICs 009 – 014 in MKI-1.[16] The huge increase for EPS is due to water use (IC number 063); excluding this impact category, the total impact of EPS is comparable to XPS.

Summarising the MKI-1 for impact categories 001 – 014 instead of for 001 – 008 does not significantly change the relative order of MKI levels for the 3 bio-based products (data not shown).

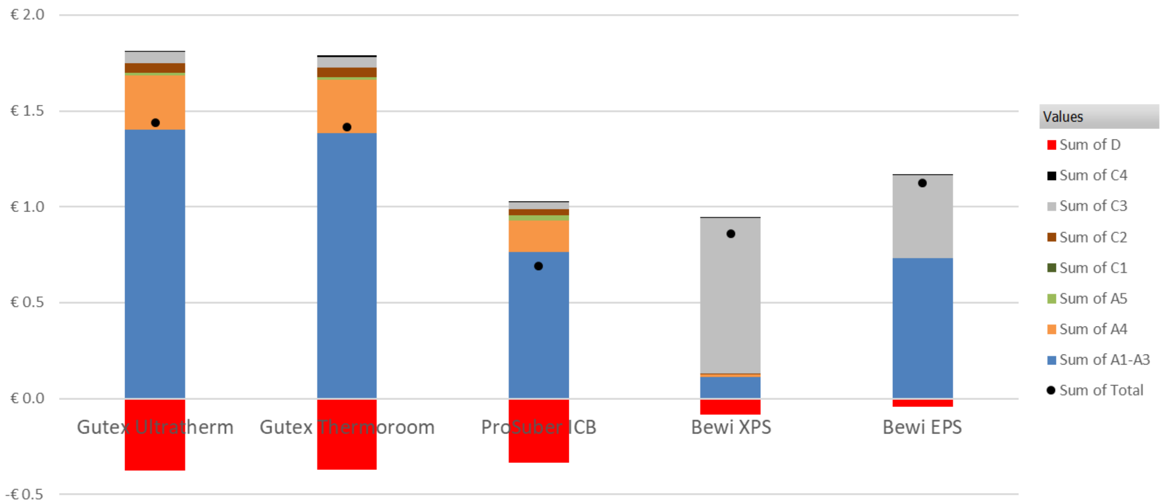

Figure 5 ***MKI-1 for pressure-resistant insulation boards. Based on ICs 001 – 008 only;[16] values for 009-014 are not included in the EPDs of the reference conventional insulation products.***

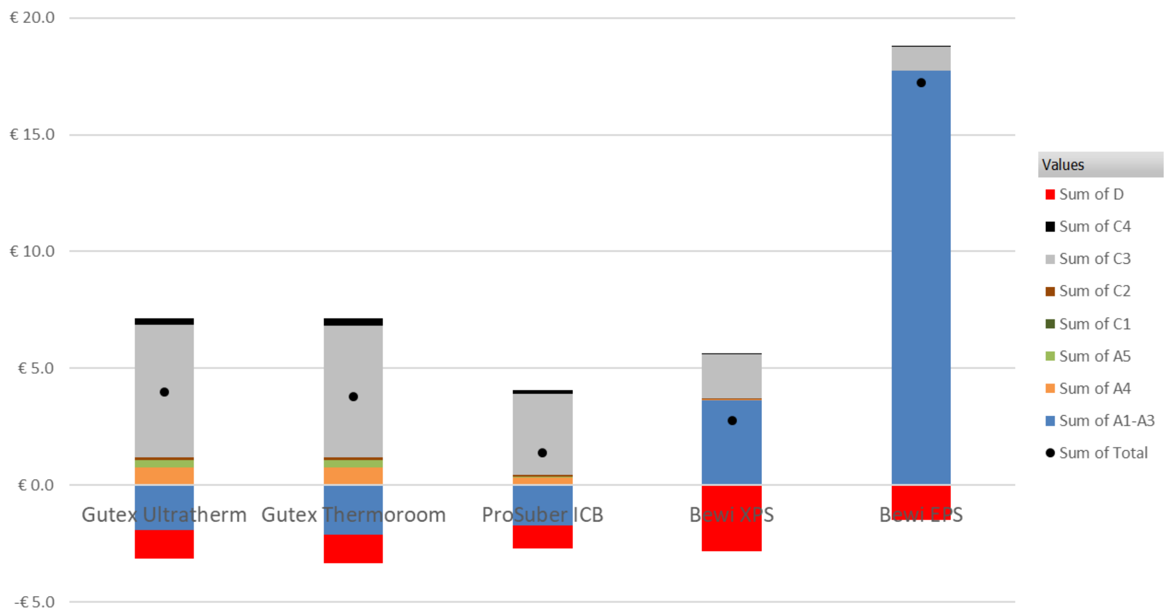

Figure 6 MKI-2 for pressure-resistant insulation boards. Based on ICs 052 – 069.[16]

In the EU, the ICs 064-069 are not-obligatory due to discussion about the robustness of their determination and calculation base.[16] These ICs, however, will be included in the Dutch method. The effect of these ICs is presented in Table 5, being largest for the wood based Gutex boards, about 25-27% increase versus 9% for Pro Suber cork and 1-7% for the XPS and EPS boards. The largest addition for wood based boards originating from particulate matter and land use. For cork, actually, land use contributes a (small) negative value due to prevention of land erosion.

Table 5 MKI-2 of pressure-resistant insulation boards for different sets of impact categories.

Product	MKI-2 for IC 052-063 (€)	MKI-2 for IC 064-069 (€)	Relative increase 064-069 vs. 052-063
Gutex Ultratherm	3.176	0.804	25.3%
Gutex Thermoroom	2.995	0.795	26.6%
Pro Suber ICB	1.259	0.116	9.3%
Bewi XPS	2.589	0.181	7.0%
Bewi EPS	17.125	0.113	0.7%

Figure 7 and Figure 8 present the GWP (IC nr 004) and Climate change total (IC nr 051) data per life cycle phases A – D for pressure-resistant insulation boards.
Whereas the value for Climate change total (051) remains similar to the GWP (IC nr 004) value for Gutex wood products (+2.6%), Pro Suber cork (-0.6%) and EPS (+5.5%), the climate change total value for XPS increased by 68%. The large increase for XPS is likely due to the blowing agent. The relatively large impact in phase A4 for the Gutex wood fibre products is due to large transportation distance by road, whereas the ProSuber cork product is mainly transported by ship. The difference in C3 for XPS and EPS is due to their difference in density.

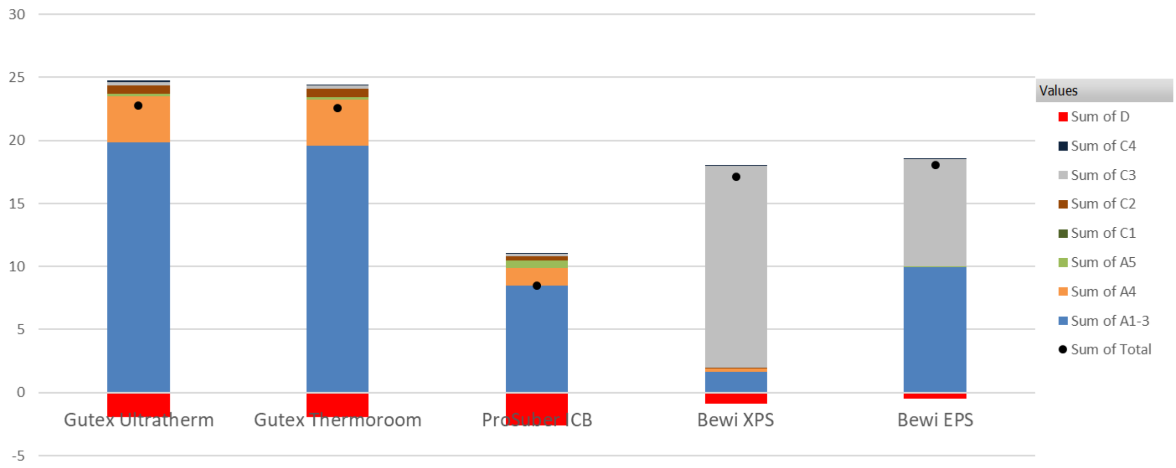

Figure 7 *GWP (IC nr 004) in kg CO_2 eq. for pressure-resistant insulation boards.*

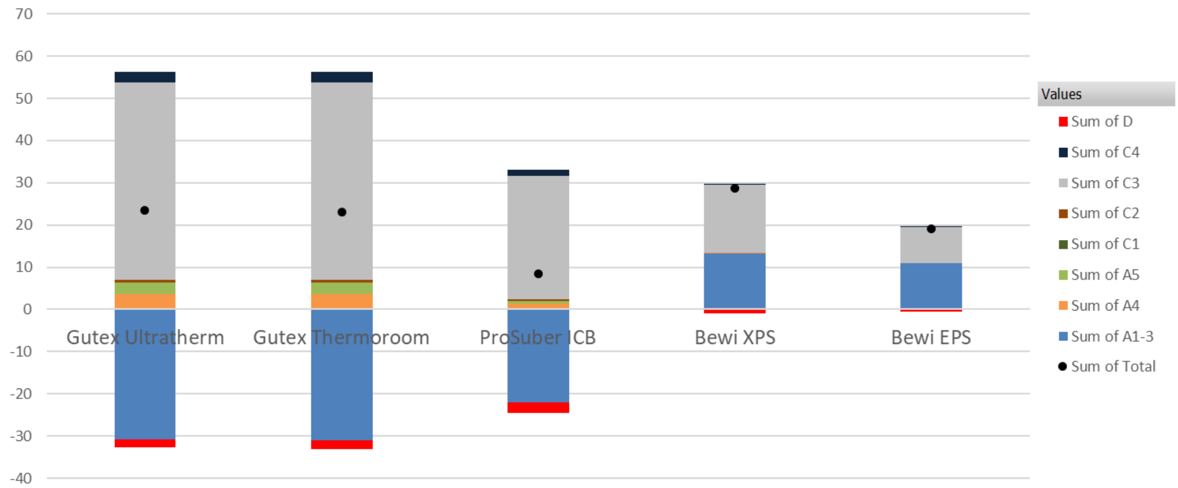

Figure 8 ***Climate change total (IC nr 051) in kg CO_2 eq. for pressure-resistant insulation boards.***

3.3.2 Flexible insulation mats

The EPDs of glass wool references do not provide set A1 data, therefore MKI-1 cannot be compared.

Figure 9 presents the MKI-2 data for impact categories 052 – 063, per life cycle phase A – D for flexible insulation mats. The MKI-2 for bio-based products is lower than for the glass wool references. Large difference with the pressure-resistant insulation boards is that the weight of the bio-based mats required to deliver an Rd of 4.7 is in the range of glass wool weights: 3.3 and 8.5 kg/m^2 versus 11.5 and 2.3 kg/m^2, respectively.

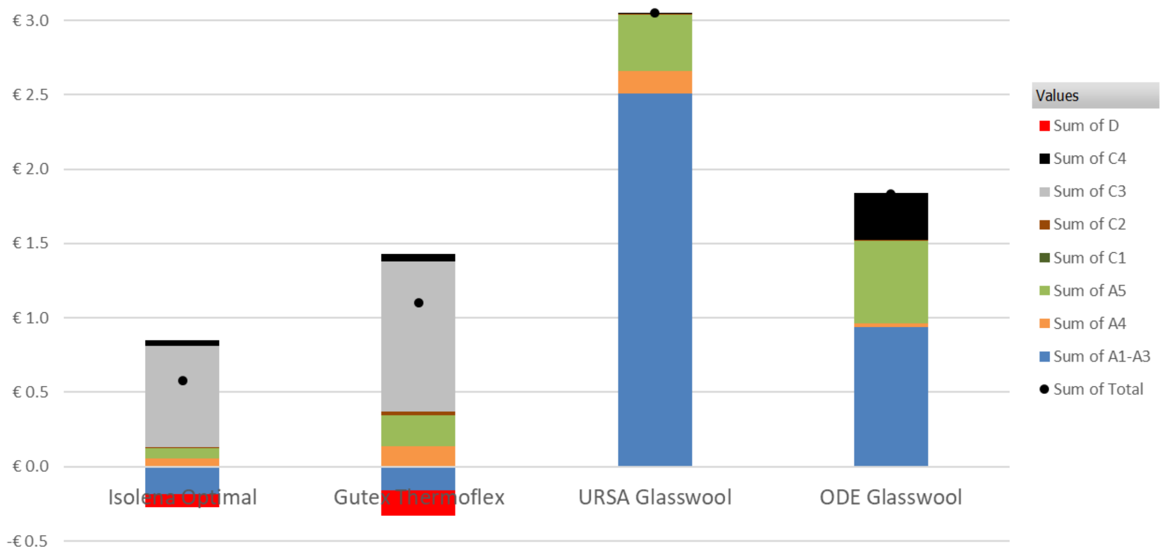

Figure 9 ***MKI-2 for flexible insulation mats. Based on ICs 052 – 063.[16]***

ICs 064 – 069 are not included in Figure 9 because these data are not included in the EPD of URSA glass wool. Whereas these ICs are not obligatory in the EU, they will be included in the Dutch determination method.[5] The effect of these ICs is presented in Table 6, being largest for the wood based Gutex boards, about 25% increase versus 14% for Isolena sheep wool and 18% for ODE glass wool.

Table 6 ***MKI-2 of flexible insulation mats for different sets of impact categories.***

Product	MKI-2 for IC 052-063 (€)	MKI-2 for IC 064-069 (€)	Relative increase
Isolena Optimal	0.578	0.083	14.3%
Gutex Thermoflex	1.104	0.273	24.8%
URSA Glasswool	3.053	-	-
ODE Glasswool	1.834	0.323	17.6%

Climate change total (IC nr 051) for bio-based mats is lower than for glass wool references (Figure 10), the relative differences being roughly similar to MKI-2 (Figure 9). Differences also relate to the weight of products required to deliver the Rd=4.7, as indicated above. The high impact for waste processing (phase C3) for the bio-based products relates to CO_2 emission counted at end-of-life, which is not the case for the glass fibre products. Further, ODE glass wool has relatively low (hardly visible) transportation impact (phase A4) compared to other products. Instead, it has a higher impact for final waste processing (phase C4).

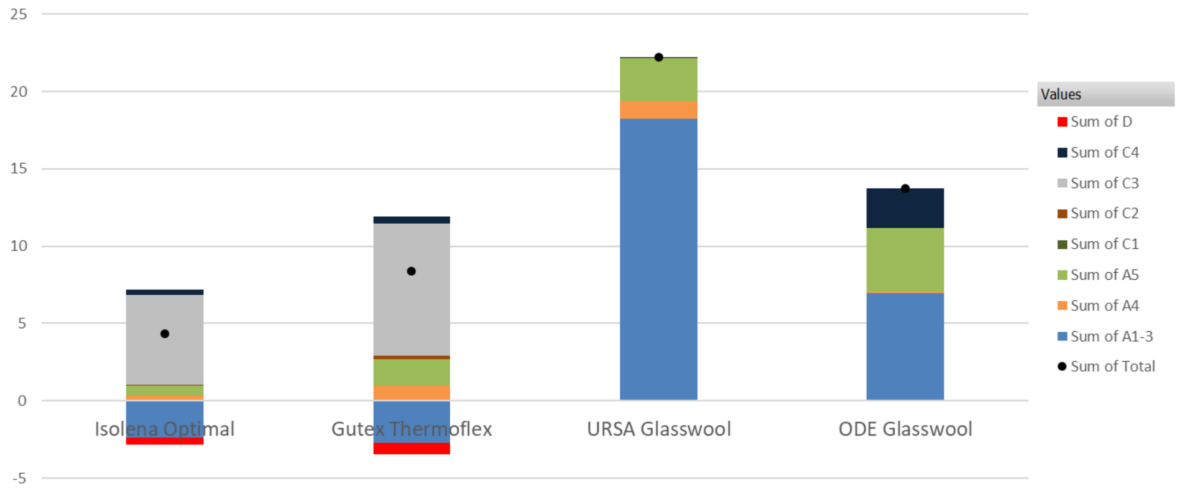

Figure 10 Climate change total (IC nr 051) in kg CO_2 eq. for flexible insulation mats.

3.3.3 Crawling space insulation

Figure 11 and Figure 12 present the MKI-1 and MKI-2 data per life cycle phase A – D for crawling space insulation. The Isoschelp shells have about 1.6 times higher MKI-1 value than EPS chips and Argex expanded clay. This relates to the weight of products required to deliver an Rd of 3.7: 314, 1.4 and 143, respectively. Further, the relatively high benefit for Expanded Clay in module D, 60% of which is resulting from GWP, largely contributes to its lower MKI-1 value compared to Isoschelp.[19] The low value of EPS chips clearly relates to the relatively very low mass required to achieve the insulation value.

ICs 009 – 014 are not included because these data are not included in the EPD of EPS chips.[16] Summarising the MKI-1 for 001 – 014 does not significantly change the relative MKI levels for the 2 other products.

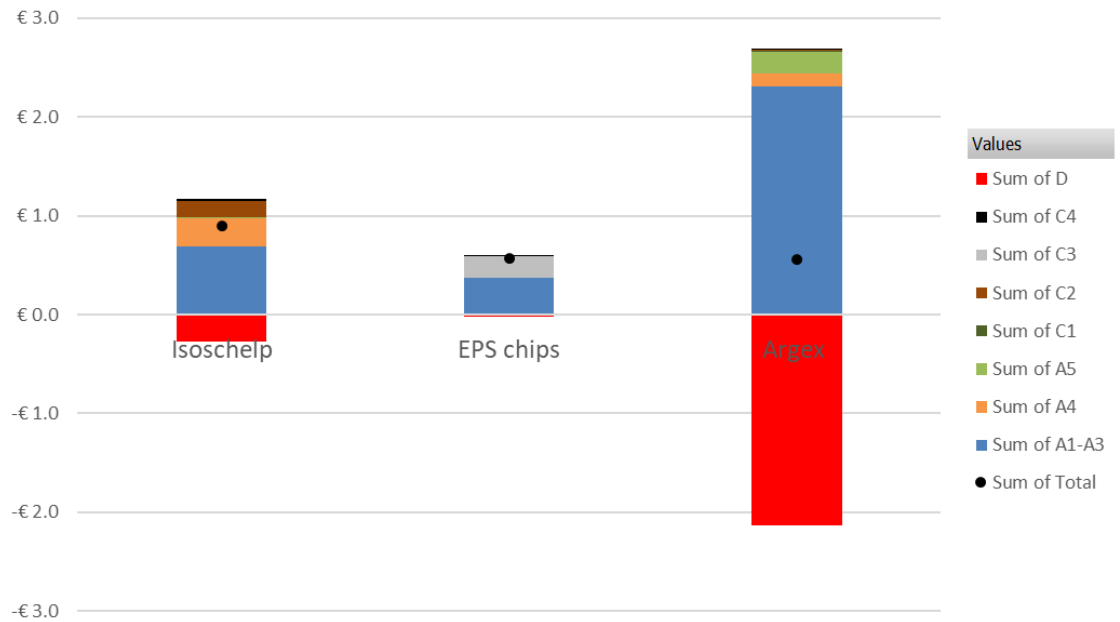

Figure 11 MKI-1 for crawling space insulation. Based on ICs 001 – 008 only; values for 009-014 are not included in the EPD of the reference EPS chips product.

For MKI-2, the relatively large amount of biogenic carbon in the heavy shells catches the eye, however, this is not the main result. Compared to MKI-1, the impact of Isoschelp shells increases less than the

[19] Considering that the benefits of reuse are achieved after 75 years only, whereas the avoided emissions are credited now, while the time horizon for GWP is 100 years, the benefit accounted in module D actually would have to relate to the time period of 25 years between 75 and 100 years from now.

Argex expanded clay and especially the EPS chips. The MKI-2 impact of EPS chips increases by as much as a factor of 15 compared to MKI-1, mainly due to water use (IC nr 063). Whereas for set A1 GWP (IC nr 004) contributes 80% to MKI-1 of EPS chips, climate change total (IC nr 051) contributes 13% to MKI-2 only, water use contributing as much as 92% (and ozone depletion contributing -7% due to benefits in phase D); the background is not clear.

The effect of ICs 064 – 069, not obligatory in the EU but included in the Dutch determination method, is presented in Table 7. The increase for the Isoschelp shells and Argex expanded clay relates to particulate matter (IC nr 064) for 96% and 92%, respectively.

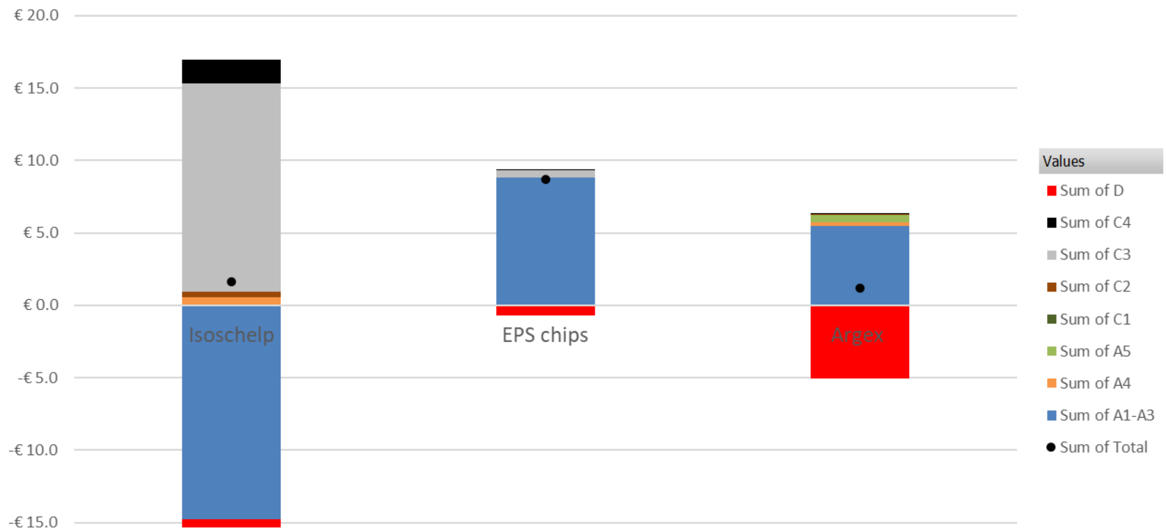

Figure 12 MKI-2 for crawling space insulation. Based on ICs 052 – 063.

Table 7 MKI-2 of crawling space insulation for different sets of impact categories.

Product	MKI-2 for IC 052-063 (€)	MKI-2 for IC 064-069 (€)	Relative increase
Isoschelp	1.641	1.190	72.5%
EPS chips	8.667	0.057	0.7%
Argex expanded clay	1.212	0.469	38.7%

3.3.4 Building blocks

Figure 13 and Figure 14 present the MKI-1 and MKI-2 data per life cycle phase A – D for building blocks for inner walls. GWP (IC nr 004) and climate change total (051) contribute 65% and 84% to MKI-1 and MKI-2 of Isohemp, respectively. For aerated concrete this is 81% and 92%, respectively. For MKI-1, the difference between the two products is mainly found in the material production phases A1 – A3. For MKI-2, the largest part of the difference is explained by landfill in the final waste processing phase (C4). Actually, hemp-lime blocks could be granulated after end-of-life and used as fertilizer, however, even if demand for lime in agriculture is way higher than the anticipated volume of hemp-lime eventually released from building demolition,[20] LCA procedures do not allow to credit this valorisation. Also construction (phase A5) adds to the difference, which is strange because the products are applied in basically the same way and have very similar density, i.e. a transportation impact is expected and the weight of 1 m^2 wall of 10 cm thickness is smaller for Isohemp compared to Bauroc AAC, 35.1 versus 38.8 kg, respectively.

[20] Considering an inner wall surface of 71.4 m^2 (terraced house), a wall thickness of 8 cm, a lime content of 200 kg/m^3, and assuming that 100,000 houses/a would be demolished (equal to the current building target) and that all houses would be containing hemp-lime inner walls, a total of 71.4 * 0.08 * 0.2 * 100,000 = 114,240 ton/a of lime would become available. Lime is applied on arable land and grassland at quantities of 0.5-3 ton/ha.a. Considering about 1,000,000 ha of grassland and about 500,000 ha of arable land, and assuming that 1 ton/ha.a of lime is applied, this means a demand of 1,500,000 ton/a. So even if 100,000 houses with hemp-lime inner walls were to be demolished per annum (which seems a significant over-estimation), less than 10% of lime demand for agriculture would be covered.

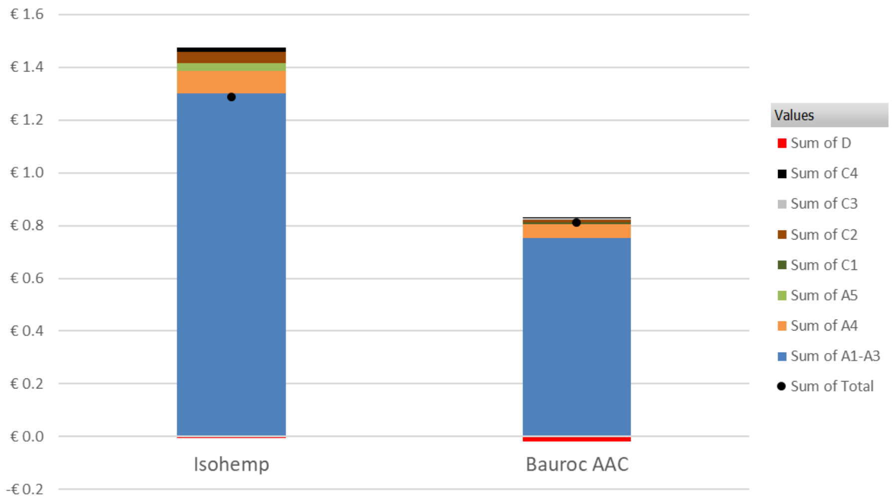

Figure 13 ***MKI-1 for building blocks for inner walls. Based on ICs 001 – 008 only;[16] values for 009-014 are not included in the EPD of the reference aerated concrete product.***

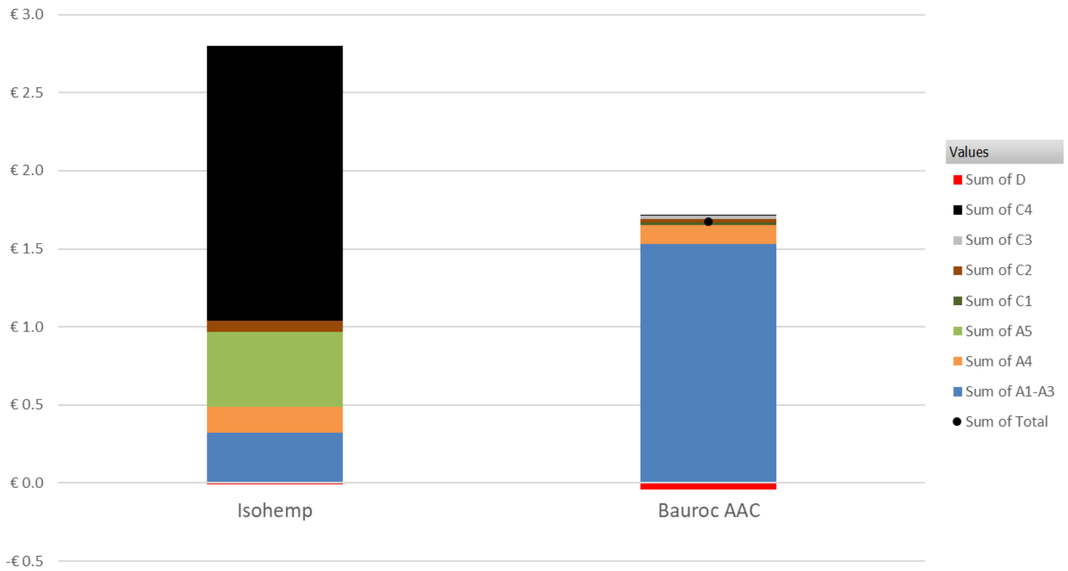

Figure 14 ***MKI-2 for building blocks for inner walls. Based on ICs 052 – 063.[16]***

Table 8 ***MKI-2 of building blocks for inner walls for different sets of impact categories.***

Product	MKI-2 for IC 052-063 (€)	MKI-2 for IC 064-069 (€)	Relative increase
Isohemp	2.374	0.600	25.3%
Bauroc AAC	1.672	-	-

3.3.5 Relative impact per impact category – Set A2 vs. set A1

The graphs below present the relative contribution of the different impact categories in the MKI-1 and MKI-2 for the products for which the complete set of impact data is given: set A1 and/or set A2. Numerical data are presented in Annex 8.

Going from set A1 to set A2, the following can be observed:

- The share of GWP/CC increases from 52 to 65% on average for the 7 bio-based products. For conventional products only 1 complete dataset is found for set A1 (expanded clay), for which GWP/CC increases from 61 to 63%. This means that for this small selection, the increase is relatively larger for bio-based than for conventional products.
- Acidification of the bio-based products decreases from on average 13 to 1%; and for the 1 conventional product from 8 to 2%.

- Human toxicity decreases from 24 to 3%; and to 18% when particulate matter is included. For the 1 conventional product human toxicity including particulate matter remains at 27%.
- The share of ozone depletion remains at virtually 0% for the bio-based products, as well as for the 1 conventional product.

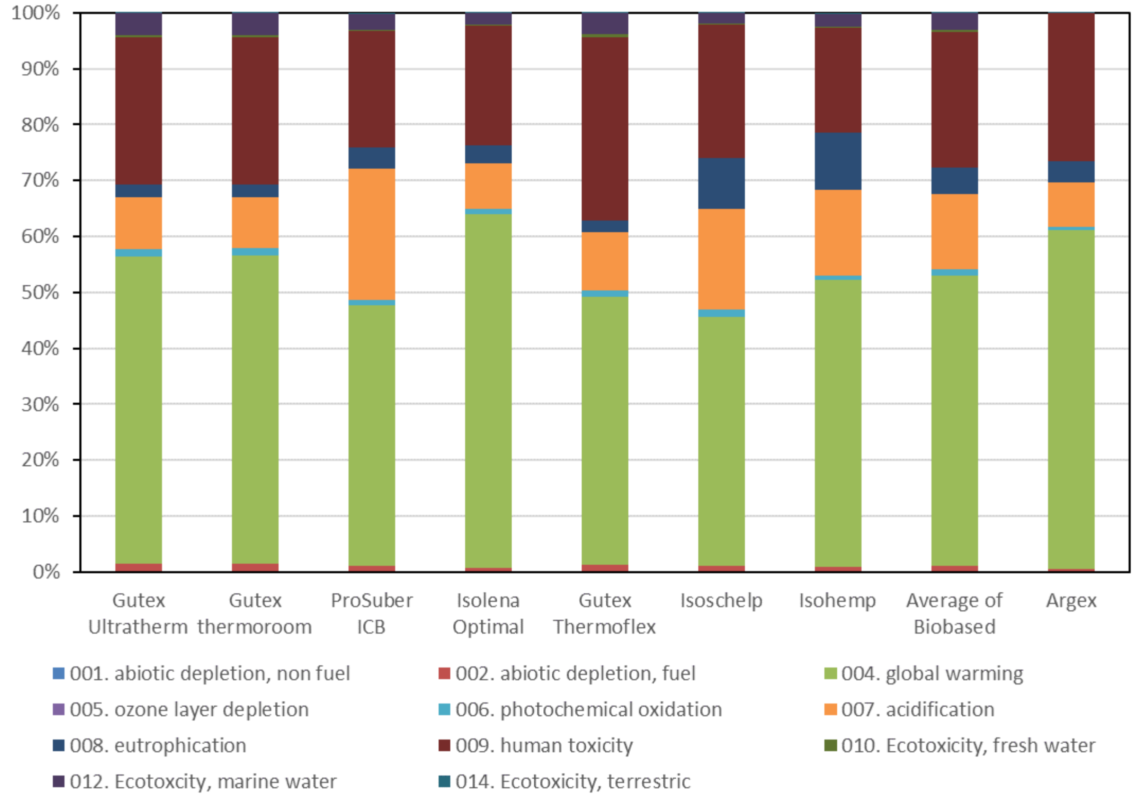

Figure 15 Relative contribution of different environmental impact categories in MKI-1 for different building products.

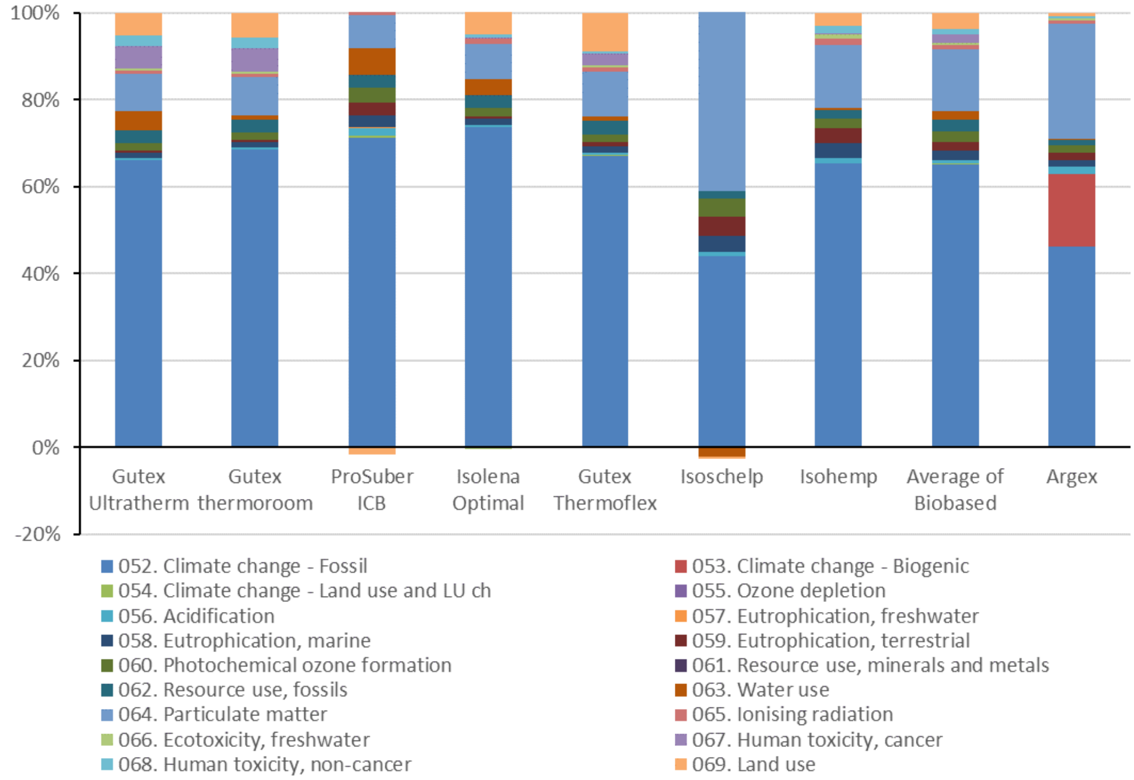

Figure 16 Relative contribution of different environmental impact categories in MKI-2 for different building products.

3.4 Conclusions

- The EPDs of the bio-based products have all been included in the Dutch NMD database, which means that they have been evaluated by an external reviewer and subsequently checked during the acceptance procedure by the NMD. Whereas the status of the EPDs of the reference products is not exactly clear, the 'valid to' dates on the EPDs indicates that a review has taken place. It is concluded that the EPDs can be compared at basic level.
- Moving from set A1 (MKI-1) to set A2 (MKI-2), in general, results in:
    - An increase of environmental impact costs for both bio-based and conventional products.
        - This is the result of the increase in number of impact categories (ICs) from 11 to 19, and an increase of the costs for climate change.
    - A relative decrease of the MKI for bio-based products compared to the conventional references. Some bio-based products exhibit lower environmental impact costs for MKI-2 than conventional products, other bio-based products decrease the gap or even close it.
- Some bio-based products have a much higher weight than their conventional references, which largely affects the environmental impact of the product at equal performance level.
- The contribution of impact categories 064 – 069, not obligatory in EU but included in the Netherlands,[16] on MKI-2 on average is larger for bio-based than for conventional products; especially for the wood fibre insulation boards and mats, and the shell insulation.

4 Effects of including biogenic carbon storage in the Determination Method

Long term storage of biogenic carbon which has been recently extracted from the atmosphere represents a benefit which can be credited, however, which is currently not included in the determination of the environmental impact of building products and the MPG of buildings. A proposal for quantifying the value of long term biogenic carbon storage in building products, in line with the Dutch Determination Method, has been drafted in a recently published report.[6] In this chapter, the effects of crediting long term biogenic carbon storage in building products on a couple of environmental impact indicators are analysed:

- Effects on global warming potential (GWP) of reference buildings,[21] according to the currently applicable Determination Method based on set A1 (sections 4.1.2, 4.2.1).
- Effects on the environmental impact of reference buildings (MPG),[21] according to the currently applicable Determination Method based on set A1 (sections 4.1.3, 4.2.2).
- Effects on Climate change (CC) of selected building products,[22] according to the new EN 15804+A2 method and set A2, for which the Dutch government is expected to take a decision in 2025 (sections 4.1.4, 4.2.3).
- Effects on the environmental cost indicator (MKI-2) of selected building products,[22] according to the new EN 15804+A2 method and set A2, for which the Dutch government is expected to take a decision in 2025 (sections 4.1.5, 4.2.4).

As explained in the mentioned report,[6] such crediting does not involve double counting, nor does it come with carbon debt in case of sustainable crop cultivation. Further it was explained that the crediting method applies to all building products, however, non-biobased materials have not recently absorbed CO_2 from the atmosphere, and therefore their biogenic carbon content factor is zero, and consequently their GWP benefit is zero.

4.1 Methodology

4.1.1 General equation to determine biogenic carbon storage benefit per product

The benefit of long term CO_2 storage in a bio-based building material, GWP_B (kg CO_2 eq.), can be determined using equation 1:[6]

$$GWP_B = m * C_C * 3.67 * GWP_{BF,T} * R_{nsv} \qquad \text{(equation 1)}$$

Calculation of the GWP benefit of each building product requires the following data:

- The dry mass (m, in tonne or kg) of the bio-based product.
    - Generally, it may be considered that bio-based materials under 'dry conditions' contain about 10-12 wt.% moisture.
    - It may be considered that bio-based building products may contain non-biobased components, such as e.g. glue.
- The biogenic carbon content (C_c, in kg C/kg product) in each of the building products.
    - Data for carbon content in bio-based materials included in this study are given in Annex 9.
- The relative global warming potential benefit factor ($GWP_{BF,100}$).
    - Based on a service life of 75 years for all products in this exercise, in line with the standard service life considered in the Dutch Determination Method, and anticipating a

[21] As defined for the analysis of the environmental impact of bio-based versus conventional houses in chapter 2 and annexes 1 and 2.

[22] As defined for the analysis of the environmental impact of bio-based versus conventional building products in chapter 3.

time horizon of 100 years as is usually considered in LCA, $GWP_{BF,T}$ can be taken from table 13 in Van den Oever et al.[6]: 0.682.

- The net biogenic carbon storage ratio (N_{nsv}). This factor is 1 for sustainably sourced wood and bio-based building materials applied in new-built houses, extension of houses and replacement of non-carbon based building elements.

4.1.2 Quantification of GWP benefit for reference houses (set A1)

In order to quantify the GWP benefit of using bio-based building products in a series of reference houses:

- 3 types of BENG reference buildings: Terraced house, semi-detached house, apartment flat M;
- 4 types of base product variants: concrete, sand-lime and their TFC and CLT based 'equivalents',

the following set of parameters have been subsequently determined:

- Dimensions for each bio-based product;
  - Several products with relatively small volume which are identical for all 4 type of product variants are not included: Adjustment frames, cavity battens, handrails, balustrades and fuse box doors.
  - A few other small items present in TFC and CLT bio-based variants are not included as well: Roof opening and insulation.
- Volumes (m^3) of each building product;
  - For TFC construction systems, so called 'wood% values' are defined which indicate the percentage of a construction area that is 'filled' with TFC wood. Such values depend on type of building system and requirements related to type of building, and facilitate quick conversion of TFC construction system area to wood volume.[23] These wood% values are given Annex 10.
- Mass (tonne dry matter) of bio-based materials in each type of building product;
  - The mass comprises the multiplication of volume (m^3) and material density (kg/m^3), taking into consideration average moisture contents and non-biobased components.
  - Densities of wood are usually reported including moisture, typically 10-12 wt.%.
  - Non-biobased components in the products covered in this study comprise glue binder. CLT and OSB are assumed to contain 5 wt.% of binder resin on dry matter basis. Density data are presented in Annex 11.
- Amount of biogenic carbon (tonne CO_2 eq.) stored per type of building product, and added up per type of house;
- GWP benefit (tonne CO_2 eq.) per type of house, considering the GWP benefit factor of 0.682 related to the service life of the house (section 4.1.1);
- Reduction of GWP impact for each of the buildings.

4.1.3 Quantification of MPG benefit for reference houses (set A1)

The environmental impact of an entire house (MPG) is calculated as the sum of monetary costs of various environmental impact categories (also see chapter 2) per m^2 gross floor surface and per annum of service life. The monetary cost (also called 'weighting factor') attributed to GWP in set A1 in the Netherlands is 0.05 €/kg CO_2 eq. (Annex 6); biogenic carbon storage in building products is credited accordingly. The gross floor surface for the reference houses is 146, 180 and 3828 m^2 for terraced house, semi-detached house and apartment building, respectively (also see Annex 1). The standard service life of a building in the Netherlands is considered to be 75 years.
The MPG benefit is calculated as the GWP benefit per house multiplied by the monetary weighting factor, divided by the gross floor surface and the service life of the house. This MPG benefit is compared to the MPG values of the reference houses, which have been determined in chapter 2 already, viz. Figure 2.

[23] https://nbvt.nl/wp-content/uploads/2023/09/NBVT-invoersinstructie-houtskeletbouw-voor-MPG.pdf

4.1.4 Quantification of Climate change benefit for selected building products (set A2)

In order to quantify the climate change (CC) benefit of using bio-based building product, the following set of parameters have been subsequently determined for 1) Rigid insulation boards; 2) Flexible insulation mats:

- Volume (m^3) of 1 m^2 of each insulation product, required to provide an Rd of 4.7:
  - Performance data and conversion factors have been described in tables 1 and 2 in section 3.2. From these data, the required volume can be calculated.
- Mass (kg) of each insulation product:
  - The densities are also included in the tables 1 and 2 in section 3.2.
- Amount of biogenic carbon (kg CO_2 eq.) in each insulation product:
  - Bio-based content data are specified in the EPDs.
  - Moisture content is based on expert judgement.
  - Biogenic carbon contents are specified in Annex 9.
- Climate change (CC) benefit (kg CO_2 eq.) per 1 m^2 of insulation product to achieve Rd=4.7, considering the CC benefit factor of 0.682 related to a standard service life of 75 years (section 4.1.1).
- Reduction of CC benefit for each insulation product.

4.1.5 Quantification of MKI-2 for selected building products (set A2)

For building products, an estimation of the total environmental impact is determined through the environmental cost indicator (MKI). The MKI is the sum of the monetary costs of various environmental impact categories. The monetary cost per impact category is the product of the impact and its monetary weighting factor. The foreseen monetary cost attributed to climate change in set A2 in the Netherlands is 0.116 €/kg CO_2 eq (Annex 7); biogenic carbon storage in building products is credited accordingly. The MKI based on set A2 is coded MKI-2.
The MKI-2 benefit is calculated as the climate change benefit (outcomes of section 4.1.4, presented in Table 11) multiplied by the monetary weighting factor. This MKI-2 benefit is compared to the MKI-2 values of rigid insulation boards and flexible insulation mats, which have been determined in chapter 3 already, viz. Figure 6 and Figure 9.
For the glass wool insulation mats, the EPDs contained data for impact categories 051 – 063 only. Therefore, the MKI-2 for the flexible insulations mats is based on these impact categories.

4.2 Results crediting biogenic carbon storage

4.2.1 Effects on GWP of reference houses (set A1)

The data required to quantify the GWP benefit of using bio-based building products in a series of reference houses are specified in:

- Annex 12: Dimensions per bio-based building products
- Annex 13: Volumes (m^3) of bio-based products
- Annex 14: Mass (tonne dry matter) of the different bio-based products
- Annex 15: Biogenic carbon (tonne CO_2 eq.) stored per type of building product, and added up per type of house;

The GWP benefits of biogenic carbon storage, GWP_B (kg CO_2 eq.) for the different reference houses, which is obtained by multiplying the biogenic carbon contents in Annex 15 and the relative global warming potential benefit factor ($GWP_{BF,100}$) of 0.682 (see section 4.1.2), are presented in Table 9 below. The effect of crediting the GWP benefit on the GWP impact is presented in the same table.
When accounting for the amount of biogenic carbon stored in different types of buildings, the GWP impact as calculated over a time horizon of 100 years decreases about 16 – 27% for TFC buildings, about 67 – 73% for CLT based buildings and about 0.2 – 4% for sand-lime and concrete buildings.

Table 9 Global warming potential in kg CO_2 eq., without (GWP; see chapter 2) and including the benefit of crediting stored biogenic carbon (GWP_B), for 3 types of reference houses and 4 types of product variants.

Type of house (Gross floor surface)	**TFC**	**CLT**	**Sand-lime**	**Concrete**
Terraced house				
GWP impact in the standard MPG (set A1)	29,300	29,200	43,000	48,500
GWP_B due to biogenic carbon storage	7,585	21,224	1,935	1,935
GWP, including GWP_B	21,715	7,976	41,065	46,565
Reduction of GWP impact in the MPG	25.9%	72.7%	4.5%	4.0%
Semi-detached house				
GWP impact in the standard MPG (set A1)	39,000	38,400	56,100	62,700
GWP_B due to biogenic carbon storage	10,735	25,752	2,784	2,784
GWP, including GWP_B	28,265	12,648	53,316	59,916
Reduction of GWP impact in the MPG	27.5%	67.1%	5.0%	4.4%
Apartment flat M				
GWP impact in the standard MPG (set A1)	1,060,000	996,000	1,570,000	1,730,000
GWP_B due to biogenic carbon storage	174,210	680,070	3,739	3,739
GWP, including GWP_B	885,790	315,930	1,566,261	1,726,261
Reduction of GWP impact in the MPG	16.4%	68.3%	0.2%	0.2%

* Smaller items not included (Adjustment frames; cavity battens; handrails; balustrades; fuse box doors; roof opening; insulation), in order to avoid too much complexity in this calculation, thus underestimating the amount of stored biogenic carbon.
* Considering 75 years service life, and a time horizon of 100 years.

4.2.2 Effects on MPG of reference houses (set A1)

In order to review the effect of the GWP benefit of biogenic carbon storage in bio-based building products on the MPG, it needs to be considered that the MPG is calculated as the sum of monetary costs of various environmental impacts (MKIs, also see chapter 2 and Annex 6) per m^2 gross floor surface and per annum of service life. The cost attributed to GWP in set A1 in the Netherlands is 0.05 €/kg CO_2 eq. (Annex 6), so biogenic carbon storage in building products can be credited accordingly. The gross floor surface for the reference houses is indicated in Table 10. The standard service life of a building in the Netherlands is considered to be 75 years.
The effect of the GWP benefit can be determined by multiplying the data from Table 9 and the monetary cost (weighting factor), and dividing by the gross floor surface and the service life. The effects for the different reference houses and product variants are presented in Table 10.

When accounting for the amount of biogenic carbon stored in different types of buildings, the total environmental impact of buildings (MPG) as calculated over a time horizon of 100 years decreases about 6 – 10% for TFC buildings, about 25% for CLT based buildings and about 0.1 – 2% for sand-lime and concrete building variants.

Table 10 Environmental cost MPG (€/m².a) for 3 types of reference houses and 4 types of product variants, without and including the benefit of crediting stored biogenic carbon.

Type of house (Gross floor surface)	TFC	CLT	Sand-lime	Concrete
Terraced house (146 m^2)				
MPG (set A1)	€ 0.392	€ 0.365	€ 0.488	€ 0.544
Benefit due to biogenic carbon storage	€ 0.035	€ 0.097	€ 0.009	€ 0.009
MPG, including biogenic carbon storage benefit	€ 0.357	€ 0.268	€ 0.479	€ 0.535
Reduction of MPG	8.8%	26.5%	1.8%	1.6%
Semi-detached house (180 m^2)				
MPG (set A1)	€ 0.412	€ 0.387	€ 0.509	€ 0.575
Benefit due to biogenic carbon storage	€ 0.040	€ 0.095	€ 0.010	€ 0.010
MPG, including biogenic carbon storage benefit	€ 0.373	€ 0.291	€ 0.498	€ 0.565
Reduction of MPG	9.6%	24.7%	2.0%	1.8%
Apartment flat M (3828 m^2)				
MPG (set A1)	€ 0.528	€ 0.485	€ 0.684	€ 0.745
Benefit due to biogenic carbon storage	€ 0.030	€ 0.118	€ 0.001	€ 0.001
MPG, including biogenic carbon storage benefit	€ 0.498	€ 0.367	€ 0.683	€ 0.744
Reduction of MPG	5.7%	24.4%	0.1%	0.1%

In Figure 17 below, the effects have been visualized by inserting a cross for the MPG including the GWP benefit in the graphs with the MPG as calculated according to the current Determination Method (as previously presented in chapter 2). The effect is small for concrete and sand-lime based houses, significant for TFC, and large for CLT based houses.

The GWP benefit may be increased by further replacing conventional building products by bio-based: Reed instead of concrete tile roofing; bio-based insulation instead of glass or stone wool insulation.

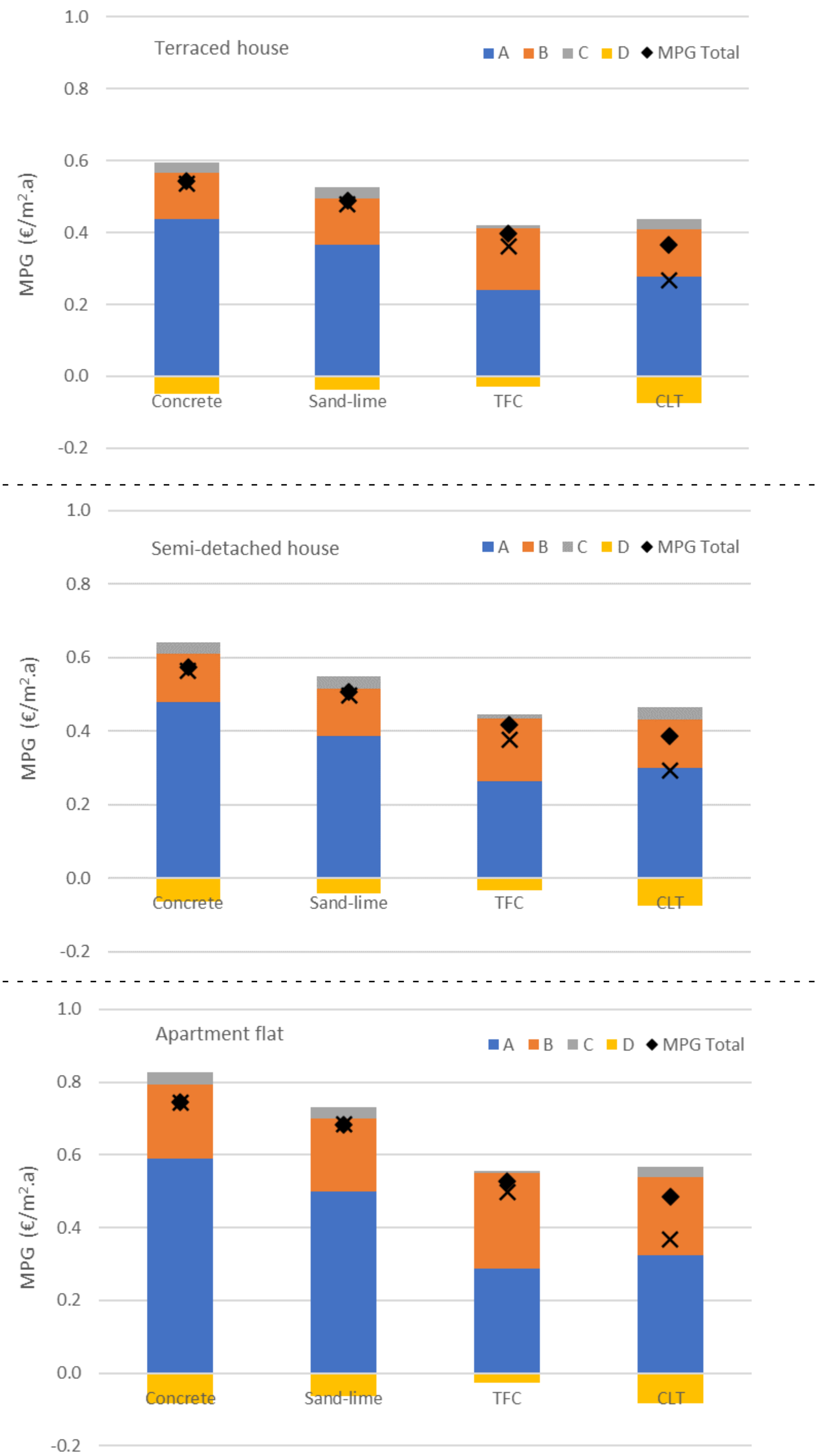

Figure 17 ***MPG of 4 different variations of construction products/methods for terraced houses (top), semi-detached houses (middle) and apartment flats (bottom). The crosses mark the MPG value including the GWP benefit; numerical data are presented in Table 10.***

4.2.3 Effects on Climate change of selected building products (set A2)

The amount of biogenic carbon stored in rigid insulation boards and flexible insulation mats at equal functional unit (Rd=4.7), as well as the data required to quantify these amounts, are specified in Table 11. The climate change (CC) benefit of rigid insulation boards and flexible insulation mats, as well as their comparison to the CC impact as determined according to set A2, are specified in Table 12.

When accounting for the amount of biogenic carbon stored in different bio-based rigid insulation boards, the CC impact of the products, as calculated over a time horizon of 100 years, becomes negative. This relates to the relatively large mass (high density) of these products and the relatively low environmental impact per unit of mass. The CC impact of the flexible insulation mats also decreases largely, by 84% – 99% to small yet positive values. The conventional products show no decrease in CC impact because they do not contain biogenic carbon.

Table 11 Amount of biogenic carbon stored in rigid insulation boards and flexible insulation mats, at equal insulation performance, Rd=4.7; together with parameters to determine these values.

Product	Mass (kg)	% Bio-based	Dry matter content (wt.%)	Carbon content (-)	Biogenic carbon stored (kg)	Biogenic carbon stored (kg CO_2 eq.)
Rigid insulation boards						
Gutex Ultratherm	31.4	95%	90%	0.493	13.24	48.60
Gutex Thermoroom	31.1	95%	90%	0.493	13.12	48.14
ProSuber ICB	21.1	100%	92%	0.685	13.28	48.75
Bewi XPS	5.0	0%	100%	0.0	0.00	0.0
Bewi EPS	2.7	0%	100%	0.0	0.00	0.0
Flexible insulation mats						
Isolena Optimal	3.3	100%	95%	0.473	1.46	5.37
Gutex Thermoflex	8.5	89%	90%	0.493	3.34	12.26
URSA Glasswool	11.5	0%	100%	0.0	0.0	0.0
ODE Glasswool	2.3	0%	100%	0.0	0.0	0.0

Table 12 Climate change impact (kg CO_2 eq.) of rigid insulation boards and flexible insulation mats, at equal insulation performance (Rd=4.7), without and including the benefit of crediting stored biogenic carbon.

Product	Climate Change as in set A2 (kg CO_2 eq.)	Biogenic carbon storage benefit (kg CO_2 eq.)	Climate change incl. benefit (kg CO_2 eq.)	Reduction in Climate change (%)
Rigid insulation boards				
Gutex Ultratherm	23.39	33.15	-9.76	142%
Gutex Thermoroom	23.14	32.83	-9.70	142%
ProSuber ICB	8.43	33.25	-24.81	394%
Bewi XPS	28.70	0.0	28.70	0%
Bewi EPS	19.06	0.0	19.06	0%
Flexible insulation mats				
Isolena Optimal	4.34	3.66	0.68	84%
Gutex Thermoflex	8.41	8.36	0.04	99%
URSA Glasswool	22.24	0.0	22.24	0%
ODE Glasswool	13.72	0.0	13.72	0%

4.2.4 Effects on MKI-2 of selected building products (set A2)

The MKI-2 benefit of rigid insulation boards and flexible insulation mats at equal functional unit (Rd=4.7), as well as their comparison to the MKI-2 impact as determined according to set A2 and based on the foreseen monetary weighting factor, are specified in Table 13.

When accounting for the amount of biogenic carbon stored in different bio-based rigid insulation boards, the MKI-2 values of the Gutex wood fibre based products, as calculated over a time horizon of 100 years, decrease largely, by about 100% to values of about zero. For the ProSuber expanded cork product, the MKI-2 becomes negative, which is due to the relatively low 'basic value for MKI-2' on one hand, and due to the high carbon content in the material on the other hand. Again, the conventional products show no decrease in MKI-2 value because they do not contain biogenic carbon.

In Figure 18 below, the effects have been visualized by inserting a cross for the MKI-2 including the CC benefit in the graphs with the MKI-2 as calculated according to the current Determination Method (as previously presented in chapter 3). The effect is very large for all bio-based insulation products, even leading to a negative value for cork, while for conventional insulation products there is no effect.

Table 13 Environmental cost MKI-2 (€/FU) of rigid insulation boards and flexible insulation mats, without and including the benefit of crediting stored biogenic carbon.

Product	MKI-2 according to set A2 (€/FU)	Biogenic carbon storage benefit (€/FU)	MKI-2 incl. benefit (€/FU)	Reduction in MKI-2 (%)
Rigid insulation boards				
Gutex Ultratherm	3.98	3.85	0.14	97%
Gutex Thermoroom	3.79	3.81	-0.02	100%
ProSuber ICB	1.37	3.86	-2.49	281%
Bewi XPS	2.77	0.0	2.77	0%
Bewi EPS	17.24	0.0	17.24	0%
Flexible insulation mats				
Isolena Optimal	0.66	0.42	0.24	64%
Gutex Thermoflex	1.38	0.97	0.41	70%
URSA Glasswool	3.05	0.0	3.05	0%
ODE Glasswool	2.17	0.0	2.17	0%

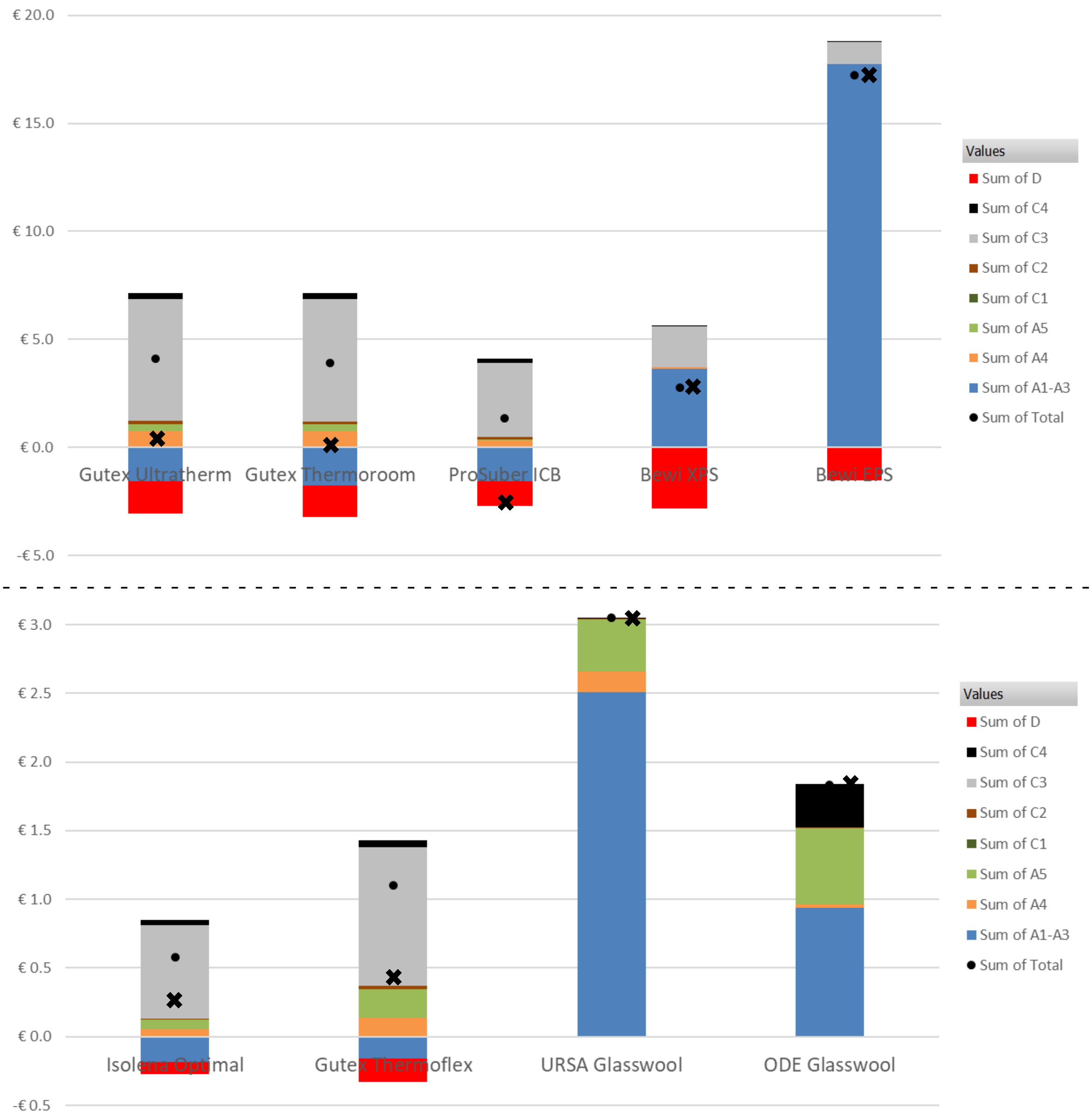

Figure 18 ***MKI-2 of rigid insulation boards (top), based on impact categories 052 – 069, and of flexible insulation mats (bottom), based on impact categories 052 - 063. The crosses mark the MKI-2 value including the CC benefit; numerical data are presented in Table 13.***

4.3 Summary and Conclusions

When biogenic carbon storage in building products is credited in the Determination Method, the following can be observed:

- The GWP impact of reference houses, as determined according to set A1, decreases by about 16 – 27% for TFC buildings, 67 – 73% for CLT based buildings and 0.2 – 5% for sand-lime and concrete building variants.
- The MPG (set A1), the total environmental impact of buildings, decreases about 6 – 10% for TFC buildings, about 25% for CLT based buildings and 0.1 – 2% for sand-lime and concrete building variants.
- The CC impact of the bio-based flexible insulation mats, as determined according to set A2, decreases by 84% – 99%, and CC impact even becomes negative for rigid insulation boards due to the relatively high density of these products.
    - Such negative impact means that production and application of such building products actually results in a net extraction of CO_2 from the atmosphere when considering the standard 100 year time horizon, thus temporarily compensating other greenhouse gas

emissions, and thus buying time to transform society into a virtually GHG emission neutral economy and creating space to reach climate goals.

- The MKI-2 (set A2) of wood fibre based insulation decreases by about 100%; for expanded cork insulation the value becomes negative due to the high carbon content in the material and the relatively low ‘basic value for MKI-2’. Again, the conventional products show no decrease in MKI-2 value because they do not contain biogenic carbon.
- The conventional (fossil based) products show no decrease for the different environmental impact parameters because they do not contain biogenic carbon.

In conclusion, crediting biogenic carbon storage in buildings largely reduces the GWP, CC and MKI of bio-based building products. Even at building level, including a significant share of non-biobased products for the TFC and CLT variants, the MPG (set A1) decreases up to 10% for TFC and about 25% for CLT houses. The MPG according to set A2 is anticipated to reduce even more, considering the increased weighting of the climate change impact category in the MKI/MPG.

Abbreviations

BENG	Nearly Energy Neutral Buildings (in Dutch 'Bijna Energieneutrale Gebouwen')
C	Carbon
C_C	Carbon content (kg/kg)
CC	Climate change
CEM	Portland cement grade, defined by the European Standard EN 197-1
CLT	Cross laminated timber
CO_2	Carbon dioxide
c.t.c.	centre to centre (distance)
EN	European Standard (from German 'Europäische Norm')
EPD	Environmental Product Declaration
EPS	Expanded polystyrene
FU	Functional unit
GWP	Global Warming Potential (kg CO_2 eq.)
GWP_B	Global Warming Potential benefit (kg CO_2 eq.)
$GWP_{BF,T}$	Global Warming Potential benefit factor at time horizon of T years
HSB	Timber frame construction (in Dutch 'Houtskeletbouw')
IC	Impact category
kg/m^2	Kilogram per square meter
kg/m^3	Kilogram per cubic meter
KNB	Royal Dutch Construction Ceramics Association (in Dutch 'Vereniging Koninklijke Nederlandse Bouwkeramiek')
kWh	kiloWatt hour
LCA	Life cycle analysis
LH	Length and height
m^2	Square meter
m^2 ufa	Usable floor area (in Dutch 'gebruiksoppervlak', gbo)
mm	Millimeter
MKI	Environmental cost indicator (in Dutch 'Milieukosten indicator')
MKI-1	Environmental cost indicator based on set A1
MKI-2	Environmental cost indicator based on set A2
MPG	Environmental impact of buildings (in Dutch 'Milieu Prestatie Gebouwen')
n/a	Not applicable
NBVG	Dutch Gypsum Industry Association (in Dutch 'Nederlandse Branche Vereniging Gips')
NBvT	Dutch trade association for the carpentry industry (in Dutch 'Nederlandse branchevereniging voor de timmerindustrie')
NMD	National Environmental Database (in Dutch 'Nationale Milieudatabase')
OSB	Oriented strand board
PIR	Polyisocyanurate
PUR	Polyurethane
PV	Photovoltaic
PVC	Polyvinyl chloride
R_C	Insulation value for a construction
R_d	Insulation value for a single building product
TFC	Timber frame construction (in Dutch 'houtskeletbouw', HSB)
VHS	Branch hinges and locks (in Dutch 'Branchevereniging hang en sluitwerk')
VKG	Trade organization for suppliers and manufacturers of plastic window frames (in Dutch 'Brancheorganisatie voor leveranciers en fabrikanten van kunststof kozijnen')
W/m^2	Watts per square meter
W/m.K	Watts per meter and per Kelvin
W/m^2.K	Watts per square meter and per Kelvin
wt.%	Weight percent
λ	Lambda, parameter for thermal conductivity

Annex 1 Materialisation of BENG reference houses

In the table below, the materialisation and key dimensions of selected BENG reference houses are presented.[10,11]

Table A1. Materialisation and key characteristics of selected BENG reference houses: Terraced house; semi-detached house; apartment flat M house.

#	Product/System *[1]	Unit	Terraced	Semi-detached	Apartment
	Gross floor surface	m^2	146	180	3828
	Usable surface	m^2	110	133	3036
	Rc of façade/ roof/ (ground) floor	$m^2.K/W$		4.7 / 6.3 / 3.7	
	U-value open sections (average)	$W/m^2.K$	1.65	1.65	1.65
	Storey height	m	2.9	2.9	3
	Number of houses *[2]	-	1	1	31
1	Foundation				
1a	Soil closures	m^2	48.6	59.9	599.7
1b	Piles	m	55.7	78.1	595.6
1c	Foundation beams	m	19.4	27.2	207.5
2	Ground floor				
2a	Floor	m^2	43.5	47.5	567.3
2b	Screed	m^2	41.4	48.7	538.9
2c	Insulation	m^2	43.5	47.5	567.3
3	Storey floors				
3a	Floors	m^2	81.1	89.3	2700
3b	Floors, covering	m^2	81.1	89.3	2700
3c	Floors, fire safety	m^2	81.1	89.3	2700
3d	Floors, sound insulation (8% wood)	m^2	74.6	82.2	2484
3e	Floors, sound insulation (CLT)		-	-	2700
3f	Screed, floating *[3]	m^2	75.8	90.2	2565
3’	Balcony/gallery floors				
3’a	Floors	m^2	-	-	225.6
3’b	Finishing (OSB) (TFC)	m^2	-	-	225.6
3’c	Decking (TFC; CLT)	m^2	-	-	225.6
3’d	Balustrade	m	-	-	225.6
4	Construction				
4a	Load bearing (separating) walls	m^2	140.7	76.4	1692
4b	Wall, Insulation (8% wood for terraced and semi-detached house; 12% wood for apartment)	m^2	129.4	70.3	1489
4c	Wall, covering	m^2	140.7	76.4	1692
4d	Wall, fire safety	m^2	140.7	76.4	1692
5	Façade, closed				
5a	Outer cavity wall	m^2	50.5	145	1241
5b	Inner cavity wall	m^2	45.4	130.5	1117
5c	Wall, covering	m^2	45.4	130.5	1117
5d	Wall, fire safety	m^2	45.4	130.5	1117
5e	Wall, insulation (22% wood) (TFC)	m^2	35.4	101.8	871
5f	Wall, insulation (Concrete; Sand-lime; CLT)	m^2	47.9	137.8	1179
6	Façade, open				
6a	Exterior doors	Pieces	2	3	45
6b	Hinges and locks	m^2	4.32	6.48	97.2
6c	Window pane exterior door (glass factor 0.51)	m^2	2.2	3.3	49.6
6d	Window frames	m^2	17.6	31	633

6e	Hinges and locks	m^2	17.6	31	633
6f	Window panes (glass factor 0.65)	m^2	11.4	20.2	411
6g	Adjusting frame	Pieces	7	12	139
6h	Window sill	m	10.4	16.8	297.6
6i	Rainscreens	m	10.4	16.8	297.6
7	Roof				
7a	Roof surface (pitched for terraced and semi-detached; flat for apartment)	m^2	70.6	86.8	567
7b	Finishing TFC-frame (OSB)	m^2	70.6	86.8	567
7c	Finishing layer for fire safety	m^2	-	-	567
7d	Insulation (CLT)	m^2	70.6	86.8	562
7e	Insulation 90% (Concrete; Sand-lime; TFC) *[4]	m^2	63.5	78.1	522
7f	Roofing *[5]	m^2	70.6	86.8	562
7g	Roof opening	Pieces	1	-	-
7h	Ballast *[5]	m^2			562
8	Built-in				
8a	Non-load bearing, system (Concrete; Sand-lime)	m^2	10.2	11.1	3181
8b	Non-load bearing, system (TFC; CLT)	m^2	71.4	83.5	3530
8c	Finishing, fire safety (TF)	m^2	142.8	167	7060
8d	Non-load bearing, solid (normal density)	m^2	36.1	42.3	3181
8e	Non-load bearing, solid (high density)	m^2	17.4	20.8	
8f	Non-load bearing, solid (high density)	m^2	7.7	9.3	349
9	Interior wall openings				
9a	Interior framework	m^2	19.9	24.9	759
9b	Interior framework-2 (fuse box)	m^2			163.5
9c	Interior doors-1	Pieces	8	10	279
9d	Interior doors-2 (fuse box)	Pieces			70
9e	Inner sill *[6]	m	1.8	1.8	125.4
10	Stairs and elevators				
10a	Stairs	Pieces	2	2	5
10b	Balustrade *[7]	m	5.1	5.1	1.1
10c	Handrails	m	10.4	10.4	24.4
10d	Elevator cabin	Pieces			1
10e	Elevator installations	Pieces			6
11	Installations, heat				
11a	Heat generation installation (heat pump)	Pieces	1	1	31
11b	Heat distribution *[8]	m^2 ufa	110.1	133.3	2854
11c	Heat release (floor heating)	m^2 ufa	110.1	133.3	2854
12	Installations, electric				
12a	Grounding	m^2 ufa	110.1	133.3	3025
12b	Lighting	m^2 ufa			625
12c	Power lines	m^2 ufa	110.1	133.3	3025
12d	Power generating systems (solar cells)	m^2	4.5	5	291.4
12e	Power supply, external *[9]	kWh	1614.1	1934	41188
13	Installations, air				
13a	Air distribution system	m^2 ufa	110.1	133.3	2854
14	Installations, water and gas distribution				
14a	Water tubes	m^2 ufa	110.1	133.3	2854
15	Drainage				
15a	Sewage piping outside	m^2 ufa	110.1	133.3	2854
15b	Sewage piping inside	m^2 ufa	110.1	133.3	2854
15c	Gutter *[10]	m	10.8	5.7	169.2
15d	Rainwater downpipe	m	12	18	169.2

Remarks:

*1 A couple of low-impact products for which no bio-based alternatives are available today and which are equal for all 4 types of construction have been omitted: (Finishes, bathroom, window sills, solid screens).

*2 The number of apartments in the apartment flat M is 33 according to the BENG reference house definition,[10,11] whereas in the GPR Material tool the number is 31.

*3 Floating screed for semi-detached house (3f) is larger than storey floor area, corresponding to the BENG reference house definition.

*4 Insulation for apartment flat M (7e) is pressure resistant insulation for concrete, sand-lime, TFC and TFC construction types because the slope of the roof is achieved by application of the insulation; area as given at 7d. For the bio-based variant, flexible insulation inside the TFC roof element has been chosen (area as in 7e).

*5 The surface for roofing and ballast for the apartment flat M (7f, 7h) is smaller than the roof surface due to application of a roof curb.

*6 The inner sill length for semi-detached house and terraced house (9e) is equal, corresponding to the BENG reference house definition.

*7 The balustrade length for the apartment flat M (10b) is smaller than for a single terraced house, corresponding to BENG reference house definition.

*8 m^2 ufa = usable floor area (in Dutch 'gebruiksoppervlak', gbo).

*9 An equivalent of the materialisation of external power supply (12e) is included in the MPG calculation via the calculation tool by a feeding a default value for the building related energy consumption, expressed in kWh.[24,25]

*10 The gutter length for the semi-detached house (15c) is shorter than for the terraced house relates to the difference in type of roofing for both BENG reference houses, corresponding to the BENG reference house definition.

[24] https://milieudatabase.nl/nl/faq/faq-milieuprestatieberekening/#accordion-item-heeft-de-nmd-een-lijst-met-referentiebouwwerken

[25] https://gprsoftware.nl/richtlijnen-invoer-mpg-berekening/

Annex 2 Definition of reference houses for MPG example calculations

The tables below describe the building products selected to design the 3 types of BENG reference houses:

- Terraced house (Table A2-1)
- Semi-detached house (Table A2-2)
- Apartment flat M (Table A2-3)

For each type of house, 4 different variations of construction products/methods have been defined:

- Conventional concrete
- Sand-lime brick
- Timber frame construction (TFC)
- Cross laminated timber (CLT)

The aim was to design the houses as equivalent as possible.

For each of these houses the environmental impact has been calculated using GPR Materiaal. The category level of EPD data selected for the MPG example calculations is presented in Annex 3.

Table A2.1 Building products selected for terraced houses.

#	Product/System	TFC	CLT	Sand-lime	Concrete
1	Foundation				
1a	Soil closures	100 mm; Sand	100 mm; Sand	100 mm; Sand	100 mm; Sand
1b	Piles	220 x 220 mm; concrete; prefab		250 x 250 mm; concrete; prefab	
1c	Foundation beams	350 x 400 mm,[26] C20/25 CEM III, cast in-situ (concrete), including reinforcement + EPS		350 x 470 mm, C20/25 CEM III, cast in-situ (concrete), including reinforcement + EPS	
2	Ground floor				
2a	Floor	Ribbed floor; concrete prefab including insulation Rc-4, Betonhuis			
2b	Screed	60mm Sand cement		60mm Sand cement	
3	Storey floors				
3a	Floors	38x220 mm, c.t.c. 600 mm Timber frame floor element representative for NBvT members	200 mm CLT floor	60 mm pre-cast slab floor + 190 mm pressure layer; C20/25 CEM III mortar including reinforcement	
3b	Floors, covering	Panel system wall not load-bearing, OSB finishing 18 mm	n/a	n/a	n/a
3c	Floors, fire safety	Panel system wall not load-bearing, plasterboard finishing 9 mm	n/a	n/a	n/a
3d	Floors, sound insulation	80 mm glass wool between timber beams (wood 8%)	n/a	n/a	n/a
3f	Screed, floating	n/a	Floating screed: 20 mm plasterboard + 10 mm rockwool (NBVG)	70 mm Sand cement	
4	Construction				
4a	Load bearing (separating) walls	38x89 mm, c.t.c. 600 mm Timber frame (wood 8%) representative for NBvT members	80 mm CLT	120 mm Sand-lime	100 mm Concrete prefab load-bearing wall, ground-level house (Betonhuis)
4b	Wall, insulation (8% wood)	Glass wool MWA 2012 boards; Rc=3.5	Stone wool MWA 2012 boards, 15mm; Rd=0.42	n/a	n/a

[26] https://www.sciencedirect.com/science/article/pii/S2210670720301414

4c	Wall, covering	Panel system wall not load-bearing, OSB finishing 9 mm	n/a	n/a	n/a
4d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm		n/a	n/a
5	Façade, closed				
5a	Outer cavity wall	100mm brick masonry KNB		100mm brick masonry KNB	
5b	Inner cavity wall (load bearing)	38x244 mm, c.t.c. 600 mm Timber frame (wood 22%) representative for NBvT members	100 mm CLT	120 mm Sand-lime	100 mm Concrete prefab non-load bearing wall, ground-level house (Betonhuis)
5c	Wall, covering	Panel system wall not load-bearing, OSB finishing 9 mm	n/a	n/a	n/a
5d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5mm	n/a	n/a	n/a
5e	Wall, Insulation (22% wood) (TFC)	Glass wool MWA 2012 boards; Rd=4.57	n/a	n/a	n/a
5f	Wall, insulation (Concrete; Sand-lime; CLT)	n/a	Glass wool MWA 2012 boards; Rd=4.07	EPS; Rd=4.42	PUR/PIR Rd=4.51
6	Façade, open				
6a	Exterior doors	Tropical wood stacking door LH 2325 x 930 mm		Tropical wood stacking door LH 2325 x 930 mm	
6b	Hinges and locks	Door handles and fittings, representative for VHS members		Door handles and fittings, representative for VHS members	
6c	Window pane exterior door (51% glass factor)	Exterior glazing HR++, coating/gas filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6d	Window frames	NBvT Asian hardwood revolving window (till 2.3 m^2), including maintenance		Polymer frame, turn-tilt window, VKG quality mark	
6e	Hinges and locks	Window handles and fittings, VHS members		Window handles and fittings, VHS members	
6f	Window panes	Exterior glazing HR++, coating/gas filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6g	Adjusting frames	Adjusting frames, untreated wood; painted		Adjusting frames, untreated wood; painted	
6h	Window sill	Concrete; 165 mm width, 58 mm height		Concrete; 165 mm width, 58 mm height	
6i	Rainscreens	EPDM; foil 50 mm width, 1 mm thickness		EPDM; foil 50 mm width, 1 mm thickness	

7	Roof				
7a	Roof surface (pitched)	38x270 mm, c.t.c. 600 mm Timber frame (wood 10%) representative for NBvT members	60 mm CLT	38x270 mm, c.t.c. 600 mm Timber frame (wood 10%) representative for NBvT members	
7b	Finishing, TFC-frame	Panel system wall not load-bearing, OSB 18 mm	n/a	Panel system wall not load-bearing, OSB 18mm	
7d	Insulation (CLT)	n/a	Glass wool MWA 2012 boards; Rc=6.0	n/a	n/a
7e	Insulation (10% wood) (Concrete; Sand-lime; TFC)	Glass wool MWA 2012 boards; Rc=6.3	n/a	Glass wool MWA 2012 boards; Rc=6.3	
7f	Roofing	Concrete tile		Concrete tile	
7g	Roof opening	Meranti roof frame; painted acryl		PVC roof frame, recycled; steel stability profile	
8	Built-in				
8a	Non-load bearing system (Concrete; Sand-lime)	n/a	n/a	100 mm Plasterboard system wall, single sheeting, including insulation (NBVG)	
8b	Non-load bearing system (TFC; CLT)	38x89 mm, c.t.c. 600 mm Timber frame for load bearing and not-load bearing element representative for NBvT members	80mm CLT	n/a	n/a
8c	Finishing, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm	n/a	n/a	n/a
8d	Non-load bearing solid (normal density)	n/a	n/a	70 mm Gypsum blocks, normal density (NBVG)	
8e	Non-load bearing solid (high density)	n/a	n/a	70 mm Gypsum blocks, high density (NBVG)	
8f	Non-load bearing solid (high density)	n/a	n/a	100 mm Gypsum blocks, high density (NBVG)	
9	Interior wall openings				
9a	Interior framework	Wood; painted alkyd		Steel; including skylight	
9c	Interior doors	Flat wooden inner door; honeycomb 2315 x 954 mm		Flat wooden inner door; honeycomb 2315 x 954 mm	
9e	Inner sill	Artificial stone; 20 mm height		Artificial stone; 20 mm height	

10	Stairs and elevators		
10a	Stairs	Softwood; 2 quarter stairs; painted	Softwood; 2 quarter stairs; painted
10b	Balustrade	European softwood; painted	European softwood; painted
10c	Handrails	European softwood; painted	European softwood; painted
11	Installations, heat		
11a	Heat generation installation (heat pump)	Ground water heat pump, including connection heat source, for space heating and option for passive cooling 3-4 kW	
11b	Heat distribution	Polyethylene/polybutylene; Central heating piping; including connectors + distributer	
11c	Heat release (floor heating)	Underfloor heating 95 W/m^2; polymer tubing	Underfloor heating 95 W/m^2; polymer tubing
12	Installations, electric		
12a	Grounding	Grounding homes	Grounding homes
12c	Power lines	Insulated installation wire + PVC jacket pipe	Insulated installation wire + PVC jacket pipe
12d	Power generating systems (solar cells)	PV; Mono-Si; pitched roof; including inverter + cables	PV; Mono-Si; pitched roof; including inverter + cables
12e	Power supply, external	Grid power; Dutch power mix, 1 kWh (flat rate)	Grid power; Dutch power mix, 1 kWh (flat rate)
13	Installations, air		
13a	Air distribution system	Air distribution system, mechanical; galvanized steel, including ventilation grills	
14	Installations, water and gas distribution		
14a	Water tubes	Polyethylene; piping + jacket pipe	Polyethylene; piping + jacket pipe
15	Disposals		
15a	Sewage piping outside	PVC; recycled; piping	PVC; recycled; piping
15b	Sewage piping inside	PVC; recycled; piping	PVC; recycled; piping
15c	Gutter	Mast gutter, Rheinzink, M37	Mast gutter, Rheinzink, M37
15d	Rainwater downpipe	PVC; recycled, diameter 80 mm; thickness 1.8 mm	PVC; recycled, diameter 80 mm; thickness 1.8 mm

Table A2.2 Building products selected for semi-detached houses.

#	Product/System	TFC	CLT	Sand-lime	Concrete
1	Foundation				
1a	Soil closures	100 mm; Sand	100 mm; Sand	100 mm; Sand	100 mm; Sand
1b	Piles	220 x 220 mm; concrete; prefab		250 x 250 mm; concrete; prefab	
1c	Foundation beams	350 x 400 mm,[26] C20/25 CEM III, cast in-situ (concrete), including reinforcement + EPS		350 x 470 mm, C20/25 CEM III, cast in-situ (concrete), including reinforcement + EPS	
2	Ground floor				
2a	Floor	Ribbed floor; concrete prefab incl. insulation Rc-4, Betonhuis		Ribbed floor; concrete prefab incl. insulation Rc-4, Betonhuis	
2b	Screed	60mm Sand cement		60mm Sand cement	

3	Storey floors				
3a	Floors	38x220 mm, c.t.c. 600 mm Timber frame floor element representative for NBvT members	200 mm CLT floor	60 mm pre-cast slab floor + 190 mm pressure layer; C20/25 CEM III mortar including reinforcement	
3b	Floors, covering	Panel system wall not load-bearing, OSB finishing 18 mm	n/a	n/a	n/a
3c	Floors, fire safety	Panel system wall not load-bearing, plasterboard finishing 9 mm	n/a	n/a	n/a
3d	Floors, sound insulation	80 mm glass wool between timber beams (wood 8%)	n/a	n/a	n/a
3f	Screed, floating	n/a	Floating screed: 20 mm plasterboard + 10 mm rockwool (NBVG)	70 mm Sand cement	
4	Construction				
4a	Load bearing (separating) walls	38x89 mm, c.t.c. 600 mm Timber frame (wood 8%) representative for NBvT members	80 mm CLT	120 mm Sand-lime	100 mm Concrete prefab load bearing wall, ground-level house (Betonhuis)
4b	Wall, insulation (8% wood)	Glass wool MWA 2012 boards; Rc=3.5	Stone wool MWA 2012 boards; Rd=0.42	n/a	n/a
4c	Wall, covering	Panel system wall not load-bearing, OSB finishing 9 mm	n/a	n/a	n/a
4d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm		n/a	n/a
5	Façade, closed				
5a	Outer cavity wall	100mm brick masonry KNB		100mm brick masonry KNB	
5b	Inner cavity wall (load bearing)	38x244 mm, c.t.c. 600 mm Timber frame (wood 22%) representative for NBvT members	100 mm CLT	120 mm Sand-lime	100 mm Concrete prefab non-load bearing wall, ground-level house (Betonhuis)
5c	Wall, covering	Panel system wall not load-bearing, OSB finishing 9 mm	n/a	n/a	n/a

5d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm	n/a	n/a	n/a
5e	Wall, Insulation (22% wood) (TFC)	Glass wool MWA 2012 boards; Rd=4.57	n/a	n/a	n/a
5f	Wall, insulation (Concrete; Sand-lime; CLT)	n/a	Glass wool MWA 2012 boards; Rd=4.07	EPS; Rd=4.42	PUR/PIR Rd=4.51
6	Façade, open				
6a	Exterior doors	Tropical wood stacking door LH 2325 x 930 mm		Tropical wood stacking door LH 2325 x 930 mm	
6b	Hinges and locks	Door handles and fittings, representative for VHS members		Door handles and fittings, representative for VHS members	
6c	Window pane exterior door (51% glass factor)	Exterior glazing HR++, coating/gas filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6d	Window frames	NBvT Asian hardwood revolving window (till 2.3 m^2), including maintenance		Polymer frame, turn-tilt window, VKG quality mark	
6e	Hinges and locks	Window handles and fittings, VHS members		Window handles and fittings, VHS members	
6f	Window panes	Exterior glazing HR++, coating/gas filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6g	Adjusting frames	Adjusting frames, untreated wood; painted		Adjusting frames, untreated wood; painted	
6h	Window sill	Concrete; 165 mm width, 58 mm height		Concrete; 165 mm width, 58 mm height	
6i	Rainscreens	EPDM; foil 50 mm width, 1 mm thickness		EPDM; foil 50 mm width, 1 mm thickness	
7	Roof				
7a	Roof surface (pitched)	38x270 mm, c.t.c. 600 mm Timber frame (wood 10%) representative for NBvT members	80 mm CLT	38x270 mm, c.t.c. 600 mm Timber frame (wood 10%) representative for NBvT members	
7b	Finishing, TFC-frame	Panel system wall not load-bearing, OSB 18 mm	n/a	Panel system wall not load-bearing, OSB 18 mm	
7c	Finishing, fire safety	n/a	n/a	n/a	n/a
7d	Insulation (CLT)	n/a	Glass wool MWA 2012 boards; Rd=5.9	n/a	n/a
7e	Insulation (10% wood) (Concrete; Sand-lime; TFC)	Glass wool MWA 2012 boards; Rc=6.3	-	Glass wool MWA 2012 boards; Rc=6.3	Glass wool MWA 2012 boards; Rc=6.3
7f	Roofing	Concrete tile	Concrete tile	Concrete tile	Concrete tile

8	Built-in				
8a	Non-load bearing system (Concrete; Sand-lime)	n/a	n/a	100mm Plasterboard system wall, single sheeting, including insulation (NBVG)	
8b	Non-load bearing system (TFC; CLT)	38x89 mm, c.t.c. 600 mm Timber frame for load bearing and not-load bearing element representative for NBvT members	80 mm CLT	n/a	n/a
8c	Finishing, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm	n/a	n/a	n/a
8d	Non-load bearing solid (normal density)	n/a	n/a	70 mm Gypsum blocks, normal density (NBVG)	
8e	Non-load bearing solid (high density)	n/a	n/a	70 mm Gypsum blocks, high density (NBVG)	
8f	Non-load bearing solid (high density)	n/a	n/a	100 mm Gypsum blocks, high density (NBVG)	
9	Interior wall openings				
9a	Interior framework	Wood; painted alkyd		Steel; including skylight	
9c	Interior doors	Flat wooden inner door; honeycomb 2315 x 954 mm		Flat wooden inner door; honeycomb 2315 x 954 mm	
9e	Inner sill	Artificial stone; 20 mm height		Artificial stone; 20 mm height	
10	Stairs and elevators				
10a	Stairs	Softwood; 2 quarter stairs; painted		Softwood; 2 quarter stairs; painted	
10b	Balustrade	European softwood; painted		European softwood; painted	
10c	Handrails	European softwood; painted		European softwood; painted	
11	Installations, heat				
11a	Heat generation installation (heat pump)	Ground water heat pump, including connection heat source, for space heating and option for passive cooling 3-4 kW			
11b	Heat distribution	Polyethylene/polybutylene; Central heating piping; including connectors + distributer			
11c	Heat release (floor heating)	Underfloor heating 95 W/m^2; polymer tubing		Underfloor heating 95 W/m^2; polymer tubing	
12	Installations, electric				
12a	Grounding	Grounding homes		Grounding homes	
12c	Power lines	Insulated installation wire + PVC jacket pipe		Insulated installation wire + PVC jacket pipe	
12d	Power generating systems (solar cells)	PV; Mono-Si; pitched roof; including inverter + cables		PV; Mono-Si; pitched roof; including inverter + cables	

12e	Power supply, external	Grid power; Dutch power mix, 1 kWh (flat rate)	Grid power; Dutch power mix, 1 kWh (flat rate)
13	Installations, air		
13a	Air distribution system	Air distribution system, mechanical; galvanized steel, including ventilation grills	
14	Installations, water and gas distribution		
14a	Water tubes	Polyethylene; piping + jacket pipe	Polyethylene; piping + jacket pipe
15	Disposals		
15a	Sewage piping outside	PVC; recycled; piping	PVC; recycled; piping
15b	Sewage piping inside	PVC; recycled; piping	PVC; recycled; piping
15c	Gutter	Mast gutter, Rheinzink, M37	Mast gutter, Rheinzink, M37
15d	Rainwater downpipe	PVC; recycled, diameter 80 mm; thickness 1.8 mm	PVC; recycled, diameter 80 mm; thickness 1.8 mm

Table A2.3 Building products selected for apartment flat M.

#	Product/System	TFC	CLT	Sand-lime	Concrete
1	Foundation				
1a	Soil closures	100 mm; Sand	100 mm; Sand	100 mm; Sand	100 mm; Sand
1b	Piles	290 x 290 mm; concrete; prefab		320 x 320 mm; concrete; prefab	
1c	Foundation beams	350 x 400 mm, C20/25 CEM III concrete, cast in-situ, including reinforcement + EPS		350 x 470 mm, C20/25 CEM III, cast in-situ (concrete), including reinforcement + EPS	
2	Ground floor				
2a	Floor	280 mm, C20/25 CEM concrete cast in-situ, including reinforcement			
2b	Screed	60 mm Sand cement		60 mm Sand cement	
2c	Insulation	EPS, Rc=3.5		EPS, Rc=3.5	
3	Storey floors				
3a	Floors	38x220 mm, c.t.c. 600 mm Timber frame floor element representative for NBvT members	200 mm CLT floor	60 mm pre-cast slab floor + 190 mm pressure layer; C20/25 CEM III mortar including reinforcement	
3b	Floors, covering	Panel system wall not load-bearing, OSB finishing 18 mm	n/a	n/a	n/a
3c	Floors, fire safety	Panel system wall not load-bearing, plasterboard finishing, 2x 12.5 mm mounted on resilient bar (acoustic)	n/a	n/a	n/a

3d	Floors, sound insulation (TFC)	100 mm glass wool between timber beams (wood 8%)	n/a	n/a	n/a
3e	Floors, sound insulation (CLT)	n/a	95 mm Stone wool Rd=2.5	n/a	n/a
3f	Screed, floating	Floating screed: 20mm plasterboard + 10mm rockwool (NBVG)		70 mm Sand cement	
3’	Balcony/gallery floors				
3’a	Floors	38x220 mm, c.t.c. 600 mm Timber frame floor element representative for NBvT members	200 mm CLT floor	250 mm Concrete, AB-FAB	
3’b	Balcony floor, water proofing	Panel system wall not load-bearing, OSB finishing 18 mm	n/a	n/a	n/a
3’c	Balcony floor, decking	Bitumen, 2 layers, completely glued		n/a	n/a
3’d	Balustrade	1200 mm height, European hardwood, sustainable forestry		1200 mm height, Aluminum, anodized	
4	Construction				
4a	Load bearing (separating) walls	38x89mm c.t.c. 400mm Timber frame[27] (wood 12%) representative for NBvT members	200mm CLT	300mm Sand-lime (Calduran)	250mm Concrete prefab AB-FAB
4b	Wall, insulation (24% wood)	Glass wool MWA 2012 boards; Rc=3.5	Stone wool MWA 2012 boards, 30mm; Rd=0.84	n/a	n/a
4c	Wall, covering	Panel system wall not load-bearing, OSB finishing 2x 9mm	n/a	n/a	n/a
4d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 2x 12.5 mm		n/a	n/a
5	Façade, closed				
5a	Outer cavity wall	100 mm brick masonry KNB		100 mm brick masonry KNB	
5b	Inner cavity wall (load bearing)	38x244 mm, c.t.c. 600 mm Timber frame (wood 22%) representative for NBvT members	100 mm CLT	120 mm Sand-lime (Calduran)	100 mm Concrete prefab AB-FAB

[27] Product card data are based on a single wall; therefore double surface area counted to obtain standard double wall for apartments.

5c	Wall, covering	Panel system wall not load-bearing, OSB finishing 9 mm	n/a	n/a	n/a
5d	Wall, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm	n/a	n/a	n/a
5e	Wall, Insulation (22% wood) (TFC)	Glass wool MWA 2012 boards; Rd=4.57	n/a	n/a	n/a
5f	Wall, insulation (Concrete; Sand-lime; CLT)		Glass wool MWA 2012 boards; Rd=4.07	EPS; Rd=4.47	PUR/PIR Rc=4.51
6	Façade, open				
6a	Exterior doors	Tropical wood stacking door LH 2325 x 930 mm		Tropical wood stacking door LH 2325 x 930 mm	
6b	Hinges and locks	Door handles and fittings, representative for VHS members		Door handles and fittings, representative for VHS members	
6c	Window pane exterior door (51% glass factor)	Exterior glazing HR++, coating/argon filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6d	Window frames	NBvT Asian hardwood revolving window (till 2.3 m^2), including maintenance		Aluminium turn-tilt window, VMRG quality mark	
6e	Hinges and locks	Window handles and fittings, VHS members		Window handles and fittings, VHS members	
6f	Window panes	Exterior glazing HR++, coating/argon filled, 4/16/4 mm		Exterior glazing HR++, coating/gas filled, 4/16/4 mm	
6g	Adjusting frames	Adjusting frames, untreated wood; painted		Adjusting frames, untreated wood; painted	
6h	Window sill	Concrete; 165 mm width, 58 mm height		Concrete; 165 mm width, 58 mm height	
6i	Rainscreens	EPDM; foil 50 mm width, 1 mm thickness		EPDM; foil 50 mm width, 1 mm thickness	
7	Roof				
7a	Roof surface (flat)	38x220 mm, c.t.c. 600 mm Timber frame (wood 8%) representative for NBvT members	100 mm CLT	60 mm pre-cast slab floor + 190 mm pressure layer; C20/25 CEM III mortar including reinforcement	
7b	Finishing, TFC-frame	Panel system wall not load-bearing, OSB 18 mm	n/a	Panel system wall not load-bearing, OSB 18 mm	
7c	Finishing, fire safety	Panel system wall not load-bearing, plasterboard finishing		n/a	n/a
7d	Insulation (Concrete; Sand-lime; CLT)	n/a	Pressure resistant wood fibre board 130 kg/m^3; Rd=5.8	XPS; Rd=6.14	XPS; Rd=6.14
7e	Insulation (8% wood) (TFC)	Pressure resistant wood fibre board 130 kg/m^3; Rc=6.3	n/a	n/a	n/a
G7f	Roofing	Bitumen, 2 layers, completely glued		Bitumen, 2 layers, completely glued	
7h	Ballast	50 mm gravel		50 mm gravel	

8	Built-in				
8b	Non-load bearing system (TFC; CLT)	38x89 mm, c.t.c. 600 mm Timber frame for not-load bearing element	80mm CLT	n/a	n/a
8c	Finishing, fire safety	Panel system wall not load-bearing, plasterboard finishing 12.5 mm	n/a	n/a	n/a
8d	Non-load bearing solid (normal density)	n/a	n/a	70 mm Gypsum blocks, normal density (NBVG)	
8f	Non-load bearing solid (high density)	n/a	n/a	100 mm Sand lime elements (Calduran)	
9	Interior wall openings				
9a	Interior framework	Wood; painted alkyd		Steel; including skylight	
9b	Interior framework-2 (fuse box)	Wood; painted alkyd		Wood; painted alkyd	
9c	Interior doors	Flat wooden inner door; honeycomb 2315 x 954 mm		Flat wooden inner door; honeycomb 2315 x 954 mm	
9d	Interior doors-2 (fuse box)	Particle board, painted alkyd		Particle board, painted alkyd	
9e	Inner sill	Artificial stone; 20mm height		Artificial stone; 20mm height	
10	Stairs and elevators				
10a	Stairs	Prefab concrete, 2.7m height, 1.1m width		Prefab concrete, 2.7m height, 1.1m width	
10b	Balustrade	1200 mm height, European hardwood, sustainable forestry		1200 mm height, Aluminum, anodized	
10c	Handrails	European softwood, sustainable forestry		60 mm Aluminum	
10d	Elevator cabin	Steel passenger elevator, enamelled		Steel passenger elevator, enamelled	
10e	Elevator installations	Steel lifting construction + counterweight, 1 building layer		Steel lifting construction + counterweight, 1 building layer	
11	Installations, heat				
11a	Heat generation installation (heat pump)	Ground water heat pump, including connection heat source, for space heating and option for passive cooling 3-4kW			
11b	Heat distribution	Polyethylene/polybutylene; Central heating piping; including connectors + distributer			
11c	Heat release (floor heating)	Underfloor heating 95 W/m^2; polymer tubing		Underfloor heating 95 W/m^2; polymer tubing	
12	Installations, electric				
12a	Grounding	Grounding homes		Grounding homes	
12b	Lighting	Lamp and fixture, 120 cm		Lamp and fixture, 120 cm	
12c	Power lines	Insulated installation wire + PVC jacket pipe		Insulated installation wire + PVC jacket pipe	
12d	Power generating systems (solar cells)	PV; Mono-Si; flat roof; including inverter + cables + support		PV; Mono-Si; pitched roof; including inverter + cables	
12e	Power supply, external	Grid power; Dutch power mix, 1 kWh (flat rate)		Grid power; Dutch power mix, 1 kWh (flat rate)	

13	Installations, air				
13a	Air distribution system	Air distribution system, heat recovery unit; Air distribution system, mechanical supply and discharge; galvanized steel, including ventilation grills			
14	Installations, water and gas distribution				
14a	Water tubes	Polyethylene; piping + jacket pipe		Polyethylene; piping + jacket pipe	
15	Disposals				
15a	Sewage piping outside	PVC; recycled; piping		PVC; recycled; piping	
15b	Sewage piping inside	PVC; recycled; piping		PVC; recycled; piping	
15c	Gutter	n/a	n/a	n/a	n/a
15d	Rainwater downpipe	PVC; recycled, diameter 80 mm; thickness 1.8 mm		PVC; recycled, diameter 80 mm; thickness 1.8 mm	

Annex 3 Category level of EPD data used for MPG example calculations

Table A3. Category level of EPD data selected for the MPG example calculations.

#	Product/System	Terraced house				Semi-detached house				Apartment flat			
1	Foundation	Concrete	Sand-lime	TFC	CLT	Concrete	Sand-lime	TFC	CLT	Concrete	Sand-lime	TFC	CLT
1a	Soil closures	3	3	3	3	3	3	3	3	3	3	3	3
1b	Piles	2	2	2	2	2	2	2	2	2	2	2	2
1c	Foundation beams	3	3	3	3	3	3	3	3	3	3	3	3
2	Ground floor												
2a	Floor	2	2	2	2	2	2	2	2	3	3	3	3
2b	Screed	3	3	3	3	3	3	3	3	3	3	3	3
2c	Insulation	-	-	-	-	-	-	-	-	3	3	3	3
3	Storey floors												
3a	Floors	2 & 3	2 & 3	2	**1**	2 & 3	2 & 3	2	**1**	2 & 3	2 & 3	2	**1**
3b	Floors, covering (OSB)	-	-	3	-	-	-	3	-	-	-	3	-
3c	Floors, fire safety	-	-	3	-	-	-	3	-	-	-	2	-
3d	Floors, sound insulation (8% wood)	-	-	3	-	-	-	3	-	-	-	3	-
3e	Floors, sound insulation (CLT)	-	-	-	-	-	-	-	-	-	-	-	3
3f	Screed, floating	3	3	-	2	3	3	-	2	3	3	2	2
3’	Balcony/gallery floors												
3’a	Floors	-	-	-	-	-	-	-	-	2	2	2	**1**
3’b	Finishing (OSB) (TFC)	-	-	-	-	-	-	-	-	-	-	3	-
3’c	Decking (TFC; CLT)	-	-	-	-	-	-	-	-	-	-	2	-
3’d	Balustrade	-	-	-	-	-	-	-	-	3	3	3	3
4	Construction												
4a	Load bearing (separating) walls	2	**1**	2	**1**	2	**1**	2	**1**	2	**1**	2	**1**
4b	Wall, Insulation (8% wood for terraced and semi-detached house; 12% wood for apartment)	-	-	3	3	-	-	3	3	-	-	3	3
4c	Wall, covering (OSB)	-	-	3	-	-	-	3	-	-	-	3	-
4d	Wall, fire safety	-	-	3	3	-	-	3	3	-	-	3	3

5	Façade, closed												
5a	Outer cavity wall	2	2	2	2	2	2	2	2	2	2	2	2
5b	Inner cavity wall	2	**1**	2	**1**	2	**1**	2	**1**	2	**1**	2	**1**
5c	Wall, covering (OSB)	-	-	3	-	-	-	3	-	-	-	3	-
5d	Wall, fire safety	-	-	3	-	-	-	3	-	-	-	3	-
5e	Wall, insulation (22% wood) (TFC)	-	-	3	-	-	-	3	-	-	-	3	-
5f	Wall, insulation (Concrete; Sand-lime; CLT)	3	3	-	3	3	3	-	3	3	3	-	3
6	Façade, open												
6a	Exterior doors	2	2	2	2	2	2	2	2	2	2	2	2
6b	Hinges and locks	2	2	2	2	2	2	2	2	2	2	2	2
6c	Window pane exterior door (glass factor 0.51)	3	3	3	3	3	3	3	3	3	3	3	3
6d	Window frames	2	2	2	2	2	2	2	2	2	2	2	2
6e	Hinges and locks	2	2	2	2	2	2	2	2	2	2	2	2
6f	Window panes (glass factor 0.65)	3	3	3	3	3	3	3	3	3	3	3	3
6g	Adjusting frame	3	3	3	3	3	3	3	3	3	3	3	3
6h	Water sill	3	3	3	3	3	3	3	3	3	3	3	3
6i	Rainscreens	3	3	3	3	3	3	3	3	3	3	3	3
7	Roof												
7a	Roof surface (pitched for terraced and semi-detached; flat for apartment)	2	2	2	**1**	2	2	2	**1**	2+3	2+3	2	**1**
7b	Finishing HSB-frame (OSB)	3	3	3	-	3	3	3	-	-	-	3	-
7c	Finishing layer for fire safety	-	-	-	-	-	-	-	-	-	-	2+3	2
7d	Insulation	-	-	-	3	-	-	-	3	3	3	3	3
7e	Insulation (10% wood)	3	3	3	-	3	3	3	-	-	-	-	-
7f	Roofing	3	3	3	3	3	3	3	3	2	2	2	2
7g	Roof opening	3	3	3	3	3	3	3	3	-	-	-	-
7h	Ballast	-	-	-	-	-	-	-	-	3	3	3	3
8	Built-in												
8a	Non-load bearing, system (Concrete; Sand-lime)	2	2	-	-	2	2	-	-	-	-	-	-
8b	Non-load bearing, system (TFC; CLT)	-	-	2	**1**	-	-	2	**1**	-	-	2	**1**
8c	Finishing, fire safety (TFC)	-	-	3	-	-	-	3	-	-	-	3	-
8d	Non-load bearing solid	2	2	-	-	2	2	-	-	2	2	-	-

8e	Non-load bearing solid	2	2	-	-	2	2	-	-	-	-	-	-
8f	Non-load bearing solid	2	2	-	-	2	2	-	-	**1**	**1**	-	-
9	Interior wall openings												
9a	Interior framework	3	3	3	3	3	3	3	3	3	3	3	3
9b	Interior framework-2 (fuse box)	-	-	-	-	-	-	-	-	3	3	3	3
9c	Interior doors-1	3	3	3	3	3	3	3	3	3	3	3	3
9d	Interior doors-2 (fuse box)	-	-	-	-	-	-	-	-	3	3	3	3
9e	Inner sill	3	3	3	3	3	3	3	3	3	3	3	3
10	Stairs and elevators												
10a	Stairs	2	2	2	2	2	2	2	2	2	2	2	2
10b	Balustrade	3	3	3	3	3	3	3	3	3	3	3	3
10c	Handrails	3	3	3	3	3	3	3	3	3	3	3	3
10d	Elevator cabin	-	-	-	-	-	-	-	-	3	3	3	3
10e	Elevator installations	-	-	-	-	-	-	-	-	3	3	3	3
11	Installations, heat												
11a	Heat generation installation (heat pump)	3	3	3	3	3	3	3	3	3	3	3	3
11b	Heat distribution	3	3	3	3	3	3	3	3	3	3	3	3
11c	Heat release (floor heating)	3	3	3	3	3	3	3	3	3	3	3	3
12	Installations, electric												
12a	Grounding	3	3	3	3	3	3	3	3	3	3	3	3
12b	Lighting	-	-	-	-	-	-	-	-	3	3	3	3
12c	Power lines	3	3	3	3	3	3	3	3	3	3	3	3
12d	Power generating systems (solar cells)	3	3	3	3	3	3	3	3	3	3	3	3
12e	Power supply, external	3a	3a	3a	3a	3a	3a	3a	3a	3a	3a	3a	3a
13	Installations, air												
13a	Air distribution system	3	3	3	3	3	3	3	3	3	3	3	3
14	Installations, water and gas distribution												
14a	Water tubes	3	3	3	3	3	3	3	3	3	3	3	3
15	Drainage												
15a	Sewage piping outside	3	3	3	3	3	3	3	3	3	3	3	3
15b	Sewage piping inside	3	3	3	3	3	3	3	3	3	3	3	3
15c	Gutter	1	1	1	1	1	1	1	1	-	-	-	-
15d	Rainwater downpipe	3	3	3	3	3	3	3	3	3	3	3	3

Annex 4 MPG example calculation results

Table A4. MPG example calculation results.

Product/System	Terraced house				Semi-detached house				Apartment flat			
MPG per phase	Concrete	Sand-lime	TFC	CLT	Concrete	Sand-lime	TFC	CLT	Concrete	Sand-lime	TFC	CLT
A	0.436	0.367	0.241	0.276	0.480	0.386	0.263	0.299	0.590	0.498	0.288	0.324
B	0.131	0.128	0.171	0.134	0.132	0.129	0.171	0.133	0.203	0.201	0.262	0.216
C	0.027	0.030	0.008	0.028	0.029	0.033	0.012	0.032	0.034	0.032	0.006	0.028
D	-0.050	-0.037	-0.029	-0.074	-0.065	-0.040	-0.034	-0.076	-0.082	-0.064	-0.027	-0.082
Total	0.544	0.489	0.392	0.365	0.575	0.509	0.412	0.387	0.745	0.684	0.528	0.485
MPG per element												
Foundation	0.037	0.037	0.031	0.031	0.042	0.042	0.035	0.035	0.019	0.019	0.016	0.016
Construction	0.056	0.024	0.032	0.027	0.025	0.010	0.014	0.012	0.085	0.033	0.029	0.028
Roofs	0.042	0.042	0.040	0.032	0.041	0.041	0.041	0.035	0.044	0.044	0.015	0.012
Climate installations	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.023	0.023	0.023	0.023
Plumbing	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
Floors	0.147	0.147	0.057	0.060	0.134	0.134	0.051	0.054	0.195	0.195	0.093	0.078
Facade	0.090	0.068	0.064	0.060	0.173	0.121	0.113	0.105	0.100	0.090	0.072	0.069
Inner walls	0.031	0.031	0.024	0.017	0.031	0.031	0.023	0.017	0.050	0.050	0.043	0.030
Electrical installations	0.108	0.108	0.108	0.108	0.101	0.101	0.101	0.101	0.223	0.223	0.223	0.223
Circulation space	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004
Terrain	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
MPG for ‘fixed elements’ in all buildings: Climate installations, plumbing, electrical installations, circulation space, terrain												
MPG	0.139	0.139	0.139	0.139	0.130	0.130	0.130	0.130	0.254	0.254	0.253	0.253
Share in total MPG	25.5%	28.4%	35.9%	38.0%	22.6%	25.5%	31.5%	33.6%	34.0%	37.1%	48.5%	52.2%
MPG share per main												
Foundation	7%	8%	8%	8%	7%	8%	8%	9%	2%	3%	3%	3%
Casco	25%	21%	26%	22%	17%	17%	20%	17%	24%	19%	18%	15%
Floors	27%	30%	15%	16%	23%	26%	12%	14%	26%	29%	18%	16%
Façade	17%	14%	17%	17%	30%	24%	27%	27%	13%	13%	14%	14%
Installations	24%	27%	34%	36%	22%	25%	30%	32%	33%	36%	48%	51%

Annex 5 List of EPDs included in the comparison of the environmental impact of building products

The tables below present the reference data to the EPDs included in this study to compare the environmental impact of bio-based versus conventional building products for 4 different applications.

Table A5.1 EPDs used for comparing environmental impact of rigid insulation boards.

Short name	Product	EPD valid to	Source
Gutex Ultratherm	Wood fibre insulation, with wax	8 Dec. 2028	This project; data in NMD[28]
Gutex Thermoroom	Wood fibre insulation, without wax	8 Dec. 2028	This project; data in NMD[29]
Pro Suber ICB	PSQ1 ISOKURK (ICB), 140mm expanded corkboard insulation	23 Nov. 2028	*[30]
Bewi EPS	Jackopor 80 EPS Sweden	22 March 2028	*[31]
Bewi XPS	Jackofoam XPS Norway	4 May 2028	*[32]

Table A5.2 EPDs used for comparing environmental impact of flexible insulation mats.

Short name	Product	EPD valid to	Source
Isolena Optimal	Sheep wool	30 March 2028	*[33]
Gutex Thermoflex	Wood fibre insulation	8 Dec. 2028	This project; data in NMD[34]
URSA Glasswool	URSA AIR Panel Alu-Alu P5858 / URSA AIR Panel Alu-Alu InCare P5858 / AIR32AK0B	20 Dec. 2027	*[35]
ODE Glasswool	Starflex & Evomineral 040	15 June 2026	*[36]

Table A5.3 EPDs used for comparing environmental impact of crawl space insulation.

Short name	Product	EPD valid to	Source
Isoschelp	Shells (from seabed)	28 June 2028	This project; data in NMD[37]
EPS chips	Wood fibre insulation	8 Dec. 2028	*[38]
Argex	Lightweight Expanded Clay Aggregate	5 Oct. 2026	*[39]

Table A5.4 EPDs used for comparing environmental impact of building blocks for inner walls.

Short name	Product	EPD valid to	Source
Isohemp	36 cm hemp lime blocks, PAL36	14 Dec. 2028	This project; data in NMD[40]
Bauroc AAC	Autoclaved aerated concrete blocks	24 May 2026	*[41]

[28] https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_94366/
[29] https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_93689/
[30] https://www.prosuber.com/wp-content/uploads/231216_EPD_geexpandeerde-kurkisolatie_PSQ1_Pro-Suber%C2%AE_ICB_expanded-cork-insulation_insulation-cork-board_ISOKURK_isolatiekurk.pdf, accessed 28 May 2024.
[31] https://www.epd-norge.no/getfile.php/1331486-1688895725/EPDer/Byggevarer/Isolasjon/NEPD-4298-3533_JACKOPOR-80-EPS-SWEDEN.pdf, accessed 28 May 2024.
[32] https://www.epd-norge.no/getfile.php/1332489-1683206813/EPDer/Byggevarer/Isolasjon/NEPD-4437-3697_JACKOFOAM-XPS-NORWAY.pdf, accessed 28 May 2024.
[33] https://www.isolena.com/en/media/wysiwyg/IW_EPD_Schafwolld_mmrolle_Optimal_30032023.pdf, accessed 28 May 2024.
[34] https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_93693/
[35] https://api.environdec.com/api/v1/EPDLibrary/Files/cef14596-db13-4e12-f73e-08dae3459152/Data, accessed 28 May 2024.
[36] https://tambour.co.il/wp-content/uploads/2018/07/EPD-ODE-12kg-002-1.pdf, accessed 28 May 2024.
[37] https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_93017/
[38] Data have been derived from Bewi EPS; further details see footnote 31.
[39] https://argex.eu/wp-content/uploads/EPD/NL_ARGEX_lightweight_expanded_clay_aggregate-Thermal.pdf, accessed 28 May 2024.
[40] https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_94584/
[41] https://bauroc.lv/uploads/sites/7/2021/06/EPD_armeeritud_tooted_allkirjaga.pdf, accessed 28 May 2024.

Annex 6 MKI weighting factors for set A1 impact categories

The table below presents the weighting set for converting EN 15804-A1 environmental impact category values into environmental impact cost indicator (MKI) values.

Table A6. Monetary weighting factors for set EN 15804-A1 impact categories to calculate MKI.

Impact category - Set A1	Unit	Weighting factor (€/unit indicator)
001. abiotic depletion, non fuel (AD)	kg Sb eq	0.16
002. abiotic depletion, fuel (AD)	kg Sb eq	0.16
004. global warming (GWP)	kg CO_2 eq	0.05
005. ozone layer depletion (ODP)	kg CFC-11 eq	30.00
006. photochemical oxidation (POCP)	kg C_2H_4	2.00
007. acidification (AP)	kg SO_2 eq	4.00
008. eutrophication (EP)	kg PO4--- eq	9.00
009. human toxicity (HT)	kg 1,4-DB eq	0.09
010. Ecotoxicity, fresh water (FAETP)	kg 1,4-DB eq	0.03
012. Ecotoxicity, marine water (MAETP)	kg 1,4-DB eq	0.0001
014. Ecotoxicity, terrestric (TETP)	kg 1,4-DB eq	0.06

Annex 7 MKI weighting factors for set A2 impact categories

The table below presents the monetary weighting set for converting EN 15804-A2 environmental impact category values into environmental impact cost indicator (MKI) values. These values are intended values,[42] not finally established at moment of publication of this report.

Table A7. Monetary weighting factors for set EN 15804-A2 impact categories to calculate MKI.

Impact category - Set A2	Unit	Weighting factor (€/unit indicator)
051. Climate change (CC total)	kg CO_2 eq	N/A
052. Climate change – Fossil (CC fossil)	kg CO_2 eq	0.116
053. Climate change – Biogenic (CC biogenic)	kg CO_2 eq	0.116
054. Climate change - Land use and LU change (CC luluc)	kg CO_2 eq	0.116
055. Ozone depletion (ODP)	kg CFC-11 eq	32
056. Acidification (AP)	mol H^+ eq	0.39
057. Eutrophication, freshwater (EP freshwater)	kg P eq	1.96
058. Eutrophication, marine (EP marine)	kg N eq	3.28
059. Eutrophication, terrestrial (EP terrestrial)	mol N eq	0.36
060. Photochemical ozone formation (POCP)	kg NMVOC eq	1.22
061. Resource use, minerals and metals (ADP elements)	kg Sb eq	0.3
062. Resource use, fossils (ADP fossil fuels)	MJ	0.00033
063. Water use (WDP)	m^3 deprived	0.00506
064. Particulate matter (PM)	disease incidence	549,750
065. Ionising radiation (IRHH)	kBq U-235 eq	0.049
066. Ecotoxicity, freshwater (ETF)	CTUe	0.00013
067. Human toxicity, cancer (HTCE)	CTUh	1,096,368
068. Human toxicity, non-cancer (HTnCE)	CTUh	147,588
069. Land use	Pt	0.000087

[42] https://open.overheid.nl/documenten/b376fac3-a074-4bac-9ad0-3c10588d465b/file

Annex 8 Relative impact per impact category in the MKI of different building products based on set A2 vs. set A1

The tables below present the relative impact per impact category according to set A1 and set A2 for different bio-based and conventional building products.

Table A8.1 Relative impact per impact category in the MKI of different building products based on set A1.

Impact category	Gutex Ultratherm	Gutex thermoroom	ProSuber ICB	Isolena Optimal	Gutex Thermoflex	Isoschelp	Isohemp	Average Bio-based	Argex
001. abiotic depletion, non fuel	0.00%	0.00%	0.00%	0.00%	0,00%	0.00%	0.00%	0,00%	0.00%
002. abiotic depletion, fuel	1.49%	1.46%	1.08%	0.79%	1,31%	1.02%	0.85%	1,14%	0.61%
004. global warming	54.89%	55.07%	46.63%	63.19%	47,80%	44.56%	51.36%	51,93%	60.61%
005. ozone layer depletion	0.00%	0.00%	0.00%	0.00%	0,00%	0.01%	0.00%	0,00%	0.00%
006. photochemical oxidation	1.39%	1.39%	0.85%	0.87%	1,19%	1.41%	0.81%	1,13%	0.48%
007. acidification	9.19%	9.03%	23.52%	8.14%	10,37%	17.85%	15.23%	13,33%	8.03%
008. eutrophication	2.25%	2.25%	3.79%	3.25%	2,23%	9.15%	10.29%	4,74%	3.62%
009. human toxicity	26.35%	26.34%	20.92%	21.43%	32,75%	23.87%	18.75%	24,34%	26.62%
010. Ecotoxicity, fresh water	0.47%	0.48%	0.16%	0.18%	0,48%	0.19%	0.29%	0,32%	0.01%
012. Ecotoxcity, marine water	3.92%	3.94%	2.78%	2.09%	3,81%	1.92%	2.25%	2,96%	0.00%
014. Ecotoxicity, terrestric	0.05%	0.05%	0.27%	0.06%	0,05%	0.05%	0.17%	0,10%	0.02%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table A8.2 Relative impact per impact category in the MKI of different building products based on set A2.

Impact category	Gutex Ultratherm	Gutex thermoroom	ProSuber ICB	Isolena Optimal	Gutex Thermoflex	Isoschelp	Isohemp	Average Bio-based	Argex
052. Climate change - Fossil	66.03%	68.45%	71.27%	73.79%	67.17%	43.95%	65.30%	65.14%	46.26%
053. Climate change - Biogenic	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.07%	0.01%	16.56%
054. Climate change - Land use and LU change	0.04%	0.04%	0.53%	0.02%	0.06%	0.00%	0.02%	0.10%	0.01%
055. Ozone depletion	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
056. Acidification	0.48%	0.48%	1.77%	0.49%	0.67%	1.02%	1.11%	0.86%	1.91%
057. Eutrophication, freshwater	0.03%	0.03%	0.03%	0.01%	0.02%	0.00%	0.05%	0.03%	0.01%
058. Eutrophication, marine	1.27%	1.30%	2.90%	1.28%	1.48%	3.64%	3.38%	2.18%	1.35%
059. Eutrophication, terrestrial	0.37%	0.36%	2.88%	0.69%	0.81%	4.37%	3.46%	1.85%	1.62%
060. Photochemical ozone formation	1.77%	1.82%	3.51%	1.91%	1.88%	4.22%	2.33%	2.49%	1.87%
061. Resource use, minerals and metals	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
062. Resource use, fossils	3.04%	3.05%	2.71%	2.96%	3.13%	1.88%	2.01%	2.68%	1.18%
063. Water use	4.32%	0.90%	6.31%	3.62%	0.90%	-2.01%	0.36%	2.06%	0.20%
064. Particulate matter	8.56%	8.75%	7.53%	8.13%	10.44%	41.52%	14.50%	14.20%	26.59%
065. Ionising radiation	0.70%	0.72%	1.15%	1.16%	0.80%	1.19%	1.45%	1.03%	0.81%
066. Ecotoxicity, freshwater	0.58%	0.61%	-0.22%	-0.39%	0.55%	0.39%	1.14%	0.38%	0.34%
067. Human toxicity, cancer	5.13%	5.34%	0.54%	0.19%	2.74%	0.08%	0.22%	2.03%	0.12%
068. Human toxicity, non-cancer	2.43%	2.54%	0.58%	0.81%	0.43%	0.39%	1.67%	1.26%	0.44%
069. Land use	5.25%	5.59%	-1.53%	5.33%	8.90%	-0.64%	2.93%	3.69%	0.72%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Annex 9 Carbon content of bio-based materials

The table below presents the biogenic carbon content in building materials included in the study.

Table A9. Carbon content of bio-based feedstock (g/kg).[6]

Feedstock	C-content (g/kg)	Feedstock	C-content (g/kg)
Spruce	493	Sheep wool	473
Meranti	512	Expanded Cork insulation	685
Hemp shives	483	Shells	120

Annex 10 'Wood %' values for TFC systems

For TFC construction systems, so called 'wood% values' are defined which indicate the percentage of a construction area that is 'filled' with TFC wood. Such values depend on type of building system and requirements related to type of building, and facilitate quick conversion of TFC construction system area to wood volume.[23] These values are presented the table below.

Table A10. Percentages of construction area 'filled' with TFC wood, the so called 'wood% values'.

#	Product/System	Terraced	Semi-detached	Apartment M
3	Storey floors	8%	8%	8%
3'	Balcony/gallery floor			8%
4	Load bearing house separating walls	8%	8%	12%
5	Façade inside walls	22%	22%	22%
7	Roof element	10%	10%	8%
8	Non-load bearing inside walls	14%	14%	14%

Annex 11 Densities of bio-based building materials

Average densities or wood species and average moisture content data have been taken from Houtvademecum.[43] CLT and OSB are assumed to contain 5 wt.% of binder resin on dry matter basis.

Table A11. Densities and biogenic carbon contents of bio-based building materials.

Product	Density as is (kg/m³)	Moisture content (wt.%)	Density at 0 wt.% moisture (kg/m³)	Density at 0 wt.% moisture, excl. non-bio-based (kg/m³)	Biogenic C-content (g/kg) *2
Softwood *1	460	12	405	405	493
Meranti	640	12	563	563	512
CLT *1	470	12	414	393	493
OSB *1	620	10	558	530	493

*1 Assumed to be Spruce based.

*2 Based on wood component only; resin binder for CLT and OSB already excluded in previous column.

[43] https://www.houtvademecum.com/

Annex 12 Definition of bio-based building products in reference houses for determining the effect of crediting biogenic carbon storage

In order to determine the value and benefit of biogenic carbon storage in bio-based building products on the environmental impact of buildings as proposed in a previous studies,[6] the volume of bio-based building products applied in houses needs to be determined. In the tables below, the bio-based building products used in conventional concrete BENG reference houses as well as in TFC and CLT alternatives are defined. The information is a combination of data presented in Annex 1 (materialisation of reference houses) and Annex 2 (definition of reference houses).

Tables below describe the building products constituting the largest volume of bio-based products used in:

- 3 types of BENG reference houses: Terraced house; semi-detached house; apartment flat M house
- for conventional concrete and sand-lime houses as well as TFC and CLT alternatives.

Table A12.1 Volume of bio-based building products selected for terraced houses, for 4 product variants.

#	Product/System	Amount	TFC	CLT	Concrete / Sand-lime
3	Storey floors				
3a	Floors	81.1 m^2	38x220 mm, c.t.c. 600 mm timber frame, 8% wood	200 mm CLT floor	n/a
3b	Floors, covering	81.1 m^2	OSB finishing 18mm	n/a	n/a
4	Construction				
4a	Load bearing (separating) walls	140.7 m^2	38x89 mm, c.t.c. 600 mm timber frame, 8% wood	80 mm CLT	n/a
4c	Wall, covering	140.7 m^2	OSB finishing 9 mm	n/a	n/a
5	Façade, closed				
5b	Inner cavity wall (load bearing)	45.5 m^2	38x244 mm, c.t.c. 600 mm timber frame, 22% wood	100 mm CLT	n/a
5c	Wall, covering	45.4 m^2	OSB finishing 9 mm	n/a	n/a
6	Façade, open				
6a	Exterior doors	2 pcs	Meranti wood stacking door, LH 2325 x 930mm		
6d	Window frames	17.6 m^2	Meranti revolving window (till 2.3 m^2)	Meranti revolving window (till 2.3 m^2)	n/a
7	Roof				
7a	Roof surface (pitched)	70.6 m^2	38x270 mm, c.t.c. 600 mm timber frame, 10% wood	60 mm CLT	38x270 mm, c.t.c. 600 mm timber frame, 10% wood
7b	Finishing, TFC-frame	70.6 m^2	OSB 18 mm	n/a	OSB 18 mm
8	Built-in				
8b	Non-load bearing system	71.4 m^2	38x89 mm, c.t.c. 600 mm Timber frame, 14% wood	80 mm CLT	n/a
9	Interior wall openings				
9a	Interior framework	19.9 m^2	Wood	Wood	n/a
9c	Interior doors	8 pcs	Flat wooden inner door; honeycomb 2315 x 954 mm		
10	Stairs and elevators				
10a	Stairs	2 pcs	Softwood; 2 quarter stairs[44]		

[44] https://nbvt.nl/wp-content/uploads/2024/09/EPD-LCA-Agrodome-BV-NBVT-Trap.pdf

Table A12.2 Volume of bio-based building products selected for semi-detached houses, for 4 product variants.

#	Product/System	Amounts	TFC	CLT	Concrete / Sand-lime
3	Storey floors				
3a	Floors	89.3 m^2	38x220 mm, c.t.c. 600 mm timber frame, 8% wood	200 mm CLT floor	n/a
3b	Floors, covering	89.3 m^2	OSB finishing 18 mm	n/a	n/a
4	Construction				
4a	Load bearing (separating) walls	76.4 m^2	38x89mm c.t.c. 600mm timber frame, 8% wood	80 mm CLT	n/a
4c	Wall, covering	76.4 m^2	OSB finishing 9 mm	n/a	n/a
5	Façade, closed				
5b	Inner cavity wall (load bearing)	130.5 m^2	38x244 mm, c.t.c. 600 mm timber frame, 22% wood	100 mm CLT	n/a
5c	Wall, covering	130.5 m^2	OSB finishing 9 mm	n/a	n/a
6	Façade, open				
6a	Exterior doors	2 pcs	Meranti wood stacking door, LH 2325 x 930mm		
6d	Window frames	31 m^2	Meranti revolving window (till 2.3 m^2)	Meranti revolving window (till 2.3 m^2)	n/a
7	Roof				
7a	Roof surface (pitched)	86.8 m^2	38x270 mm, c.t.c. 600 mm timber frame, 10% wood	80 mm CLT	38x270 mm, c.t.c. 600 mm timber frame, 10% wood
7b	Finishing, TFC-frame	86.8 m^2	OSB 18 mm	n/a	OSB 18 mm
8	Built-in				
8b	Non-load bearing system	83.5 m^2	38x89 mm, c.t.c. 600 mm timber frame, 14% wood	80 mm CLT	n/a
9	Interior wall openings				
9a	Interior framework	24.9 m^2	Wood	Wood	n/a
9c	Interior doors	10 pcs	Flat wooden inner door; honeycomb 2315 x 954 mm		
10	Stairs and elevators				
10a	Stairs	2 pcs	Softwood; 2 quarter stairs[44]	Softwood; 2 quarter stairs	Softwood; 2 quarter stairs

Table A12.3 ***Volume of bio-based building products selected for apartment flat M, for 4 product variants.***

#	Product/System	Amounts	TFC	CLT	Concrete / Sand-lime
3	Storey floors				
3a	Floors	2700 m^2	38x220 mm, c.t.c. 600 mm timber frame, 8% wood	200 mm CLT floor	n/a
3b	Floors, covering	2700 m^2	OSB finishing 18 mm	n/a	n/a
3’	Balcony/gallery floors				
3’a	Floors	225.6 m^2	38x220 mm, c.t.c. 600 mm timber frame, 8% wood	200 mm CLT floor	n/a
3’b	Balcony floor, water proofing	225.6 m^2	OSB finishing 18 mm	n/a	n/a
3’d	Balustrade	225.6 m^2	1200 mm height, European hardwood	1200 mm height, European hardwood	n/a
4	Construction				
4a	Load bearing (separating) walls	1692 m^2	38x89 mm, c.t.c. 400 mm timber frame, 12% wood	200 mm CLT	n/a
4c	Wall, covering	1692 m^2	OSB finishing 2x 9 mm	n/a	n/a
5	Façade, closed				
5b	Inner cavity wall (load bearing)	1117 m^2	38x244 mm, c.t.c. 600 mm timber frame, 22% wood	100 mm CLT	n/a
5c	Wall, covering	1117 m^2	OSB finishing 9 mm	n/a	n/a
6	Façade, open				
6a	Exterior doors	45 pcs	Meranti wood stacking door, LH 2325 x 930 mm		
6d	Window frames	633 m^2	Meranti revolving window (till 2.3 m^2)	Meranti revolving window (till 2.3 m^2)	n/a
7	Roof				
7a	Roof surface (flat)	567 m^2	38x220 mm, c.t.c. 600 mm timber frame, 8% wood	100 mm CLT	n/a
7b	Finishing, TFC-frame	567 m^2	OSB 18 mm	n/a	OSB 18 mm
7d	Insulation (CLT)	562 m^2		Wood fibre board 130 kg/m^3; Rd=5.8	
7e	Insulation (8% wood) (TFC)	522 m^2	Wood fibre board 130 kg/m^3; Rc=6.3		
8	Built-in				
8b	Non-load bearing system	3530 m^2	38x89 mm, c.t.c. 600 mm timber frame, 14% wood	80 mm CLT	n/a
9	Interior wall openings				
9a	Interior framework	759 m^2	Wood	Wood	n/a
9b	Interior framework-2 (fuse box)	163.5 m^2	Wood	Wood	Wood

Annex 13 Volumes of bio-based building products in reference houses

Based on the dimensions for bio-based building products specified in Annex 12, in the tables below the volumes of these products are presented.
Smaller items such as adjustment frames, cavity battens, handrails, balustrades, fuse box doors, roof openings and insulation have not been included to limit complexity, thus also providing conservative values for biogenic material volume.

Table A13.1 Volumes (m^3) and kind of the main bio-based building products for a reference terraced house, for 4 product variants.

#	Product/System	TFC	CLT	Concrete / Sand-lime
3a	Storey floors	1.43 TFC	16.22 CLT	
3b	Floor covering	1.46 OSB		
4a	Load baring (separating) walls	1.00TFC	11.26 CLT	
4c	Wall covering	1.27 OSB		
5b	Inner cavity wall	2.44 TFC	4.54 CLT	
5c	Wall covering	0.41OSB		
6a	Exterior doors	0.21 Meranti	0.21 Meranti	0.21 Meranti
6d	Window frames	0.42 Meranti	0.42 Meranti	
7a	Roof element	1.91 TFC	4.24 CLT	1.91 TFC
7b	Roof inner covering	1.27 OSB		1.27 OSB
8b	Inner wall	0.89 TFC	5.71 CLT	
9a	Interior framework	0.224 Sawn wood	0.224 Sawn wood	
10a	Stairs	EPD gives biogenic carbon and ‘CO_2 storage’ per stairs; directly included in Annex 15		
	CLT total		41.96	
	Spruce total	7.89	0.22	1.91
	Meranti total	0.63	0.63	0.21
	OSB total	4.41		1.27

Table A13.2 Volumes (m^3) and kind of the main bio-based building products for a reference semi-detached house, for 4 product variants.

#	Product/System	TFC	CLT	Concrete / Sand-lime
3a	Storey floors	1.57 TFC	17.86 CLT	
3b	Floor covering	1.61 OSB		
4a	Load baring (separating) walls	0.54 TFC	6.11 CLT	
4c	Wall covering	0.69OSB		
5b	Inner cavity wall	7.01TFC	13.05 CLT	
5c	Wall covering	1.17 OSB		
6a	Exterior doors	0.32 Meranti	0.32 Meranti	0.32 Meranti
6d	Window frames	0.72 Meranti	0.72 Meranti	
7a	Roof element	2.34 TFC	6.94 CLT	2.34 TFC
7b	Roof inner covering	1.56 OSB		1.56 OSB
8b	Inner wall	1.04TFC	6.68 CLT	
9a	Interior framework	0.28 Sawn wood	0.28 Sawn wood	
10a	Stairs			
	CLT total		50.65	
	Spruce total	12.79	0.28	2.34
	Meranti total	1.04	1.04	0.32
	OSB total	5.03		1.56

Table A13.3 Volumes (m³) and kind of the main bio-based building products for a reference apartment flat M, for 4 product variants.

#	Product/System	TFC	CLT	Concrete / Sand-lime
3a	Storey floors	47.52 TFC	540.0 CLT	
3b	Floor covering	48.60 OSB		
3’a	Balcony floors	3.97 TFC	45.1 CLT	
3’b	Balcony floor covering	4.06 OSB		
4a	Load baring (separating) walls	18.07 TFC	338.5 CLT	
4c	Wall covering	30.46 OSB		
5b	Inner cavity wall	59.96 TFC	111.7 CLT	
5c	Wall covering	10.05 OSB		
6a	Exterior doors	4.73 Meranti	4.73 Meranti	4.73 Meranti
6d	Window frames	8.36 Meranti	8.36 Meranti	
7a	Roof element	12.48 TFC	56.7 CLT	
7b	Roof inner covering	10.21 OSB		
8b	Inner wall	43.98 TFC	282.4 CLT	
9a	Interior framework	7.82 Sawn wood	7.82 Sawn wood	
9b	Interior framework (fuse box)	0.65 Sawn wood	0.65 Sawn wood	0.65 Sawn wood
10a	Stairs			
	CLT total		1374.4	
	Spruce total	194.46	8.47	0.65
	Meranti total	13.09	13.09	4.73
	OSB total	103.39	0.68	

Annex 14 Mass of bio-based building products in reference houses

Based on the building product volumes specified in Annex 13 and the densities at 0 wt.% moisture specified in Annex 11, the mass is calculated and presented in the table below.

Table A14. Mass (tonne) on dry matter basis of bio-based building products for 3 types of reference houses and for 4 product variants.

Product/System	TFC	CLT	Concrete / Sand-lime
Terraced house			
CLT		16.49	
Spruce	3.19	0.091	0.77
Meranti	0.36	0.36	0.128
OSB	2.34		0.67
Semi-detached house			
CLT		19.90	
Spruce	5.18	0.11	1.08
Meranti	0.58	0.58	0.20
OSB	2.67		0.97
Apartment flat M (33 apartments)			
CLT		540	
Spruce	78.72	3.4	0.26
Meranti	7.37	7.4	2.66
OSB	54.81		

Annex 15 Amounts of biogenic carbon stored in reference houses

Based on the mass data specified in Annex 14, the biogenic carbon content specified in Annex 11, and the mass ratio between CO_2 and carbon, the amount of CO_2 'stored' [45] in the bio-based building products can be calculated. To account for the service life of 75 years, a benefit factor of 0.682 needs to be taken into account (section 4.1.1).
In the table below, the amounts of biogenic carbon, expressed in tonne CO_2 equivalent, per main bio-based building product for each of the 3 types of reference houses and the 4 product variants are presented.

Table A15. ***Amount of biogenic carbon (tonne CO_2 equivalent) stored in bio-based building products for 3 types of reference houses and 4 product variants; considering 75 years service life, and a time horizon of 100 years.***

Product/System	TFC	CLT	Concrete / Sand-lime
Terraced house			
CLT		29.83	
Spruce	5.78	0.16	1.40
Meranti	0.67	0.67	0.22
OSB	4.23		1.22
Stairs[46]	0.45	0.45	
TOTAL	11.12	31.12	2.84
Semi-detached house			
CLT		36.00	
Spruce	9.36	0.21	1.95
Meranti	1.10	1.10	0.38
OSB	4.83		1.75
Stairs[46]	0.45	0.45	
TOTAL	15.74	37.76	4.08
Apartment flat M			
CLT		977.1	
Spruce	142.4	6.2	0.48
Meranti	13.9	13.9	5.00
OSB	99.2		
TOTAL	255.4	997.2	5.48

[45] Actually, the CO_2 extracted from the atmosphere by plants during growing is incorporated in the plant structure as biogenic carbon. 3.67 tonne of CO_2 extracted from the atmosphere is converted into 1 tonne of biogenic carbon in plants. The expression 'stored CO_2' in fact is therefore not misleading as far as CO_2 extraction and removal is concerned, however, physically speaking the CO_2 gas as such cannot be detected in the plants anymore as it has converted into plant material: cellulose, lignin, etc.

[46] https://nbvt.nl/wp-content/uploads/2024/09/EPD-LCA-Agrodome-BV-NBVT-Trap.pdf

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