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analysis, calculation model and stakeholder perspectives

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Regulation on carbon emissions for buildings with special conditions: analysis, calculation model and stakeholder perspectives

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Abstract. Climate change enhances the focus on reducing global greenhouse gases from the construction industry since it is responsible for 37% of the emissions. Several nations are implementing regulating laws by requiring life cycle assessments and by setting a threshold of CO_2e emissions. In the case of Denmark, the valid limit value of 12 kg CO_2e/m^2/year is based primarily on a sample of conventional buildings consisting of residential and office buildings. Initially, 90% of all new buildings are expected to comply with this value, while the remaining 10% must apply strategies for carbon reduction. Some building typologies that need to serve specific functions might not be able to reduce emissions due to special conditions, which will result in additional carbon emissions, and thus, exceed the limit value. This study identifies special conditions, such as hygiene requirements, that can lead to exceeding the limit value and recommends adaptation to handle the allowable additional carbon emissions in building regulations. The findings of the study are useful for policymakers that must decide how to handle special conditions of buildings in regulations.

Keywords. Regulations, life cycle assessment, carbon emissions, limit value, special conditions

1. Introduction

The Paris Agreement helps nations to recognize the importance of implementing laws that aim to reduce carbon emissions in different sectors or industries. The construction and building industries are responsible for 37% of global greenhouse gas emissions [1] and reducing carbon emissions from these industries is crucial to achieving climate agreements. Therefore, several EU nations have either implemented regulatory laws or are planning to do so, where life cycle assessment (LCA) will be the method used to document carbon emissions from buildings. Since 2020, in France, requirements for preparing LCAs for residential buildings are in place, and there are also limited values for carbon emissions. In Germany, the BNB requires LCA for all new public buildings. Moreover, carbon declarations for upfront emissions of buildings are required in Sweden, and limit values are expected to be introduced no later than 2027 [2]. On the EU level, the new revision of the Energy Building Performance Directive also expects to introduce requirements for the life-cycle global warming potential of all large new buildings by 2027 and for all new buildings by 2030[3]. Denmark implemented new regulations in 2023 for assessing the carbon emissions of new buildings. The regulation requires life cycle assessments to be prepared for all new buildings and buildings with a heated floor area greater than 1,000 m^2, must comply with a limit value of 12 kg CO_2e/m^2/year, with a reference study period of 50 years [4].

1.1. Aim of the study
According to studies investigating the CO_2e emissions from conventional and Danish buildings, the median embodied carbon (EC) emission of conventional buildings is 7.3 kg CO_2e/m^2/year, over a reference study period of 50 years [5]. If those buildings were built in 2023, complying with the limit value would not be problematic. However, this median value primarily represents residential and office buildings. Thus, there is a need to expand knowledge of other building typologies that might not be able to comply with the limit value, and if so, what special conditions cause additional use of materials and an increase in carbon emissions, which lead to exceeding the limit value. Currently, no Danish studies investigate the carbon emissions of buildings, that are constructed at a smaller scale than conventional residential and office buildings, therefore, no knowledge of potential challenges in carbon emissions is evident.

Motivated by this, the study investigates and defines special conditions, which can result in additional embodied carbon emissions from building constructions. A simple calculation model is proposed to handle additional carbon emissions from special conditions in building regulations. While the study is developed within the Danish context, the findings can inspire other nations to investigate non-conventional buildings and their associated carbon emissions.

2. Method and materials

2.1. Qualitative study
Ten stakeholders were invited to participate in the study. Overall, the stakeholders were asked to provide specific examples of buildings with potential special conditions. They were invited to three workshops that collectively aimed to define, firstly, the design challenges faced with different building typologies, secondly, the challenging special conditions, and lastly, a method for determining the allowable additional impact applicable in the building regulation.

The stakeholders provided 51 building examples in total, which they *assumed* were affected by special conditions. Those potentially affected buildings are analysed to identify special conditions that cause additional carbon emissions. The collected building cases were 4 hospitals, 4 retail, 8 school- and day-care, 9 multi-family houses, 9 offices, 11 production- and logistics, and 6 others.

2.2. Quantitative study
To identify and understand the influence of carbon emissions from special conditions, the 51 building cases are analysed using life cycle assessments [6]. The functional unit is one square meter gross floor area over a reference study period of 50 years (kg CO_2e/m^2/year). Embodied carbon emissions associated with life cycle modules A1-3, B4, and C3-4 are determined according to EN 15978:2012 [7]. The LCA software used is LCAbyg version 5.2.1.0.

An additional 60 buildings from an existing study [5] are used to define LCA-based reference values for building construction, which are also used to define a calculation model for determining additional carbon emissions. These reference values are listed in Table 1.

2.3. Definition of special condition
Based on the workshops and the analysis of several buildings, a special condition is defined as: *" a condition that causes additional embodied carbon emissions from one or more building constructions, resulting in non-compliance with the limit value. A construction is affected by special conditions if it cannot be optimized without altering the function or purpose of the building itself."* Conditions that do not meet the above definition are assumed to have optimization potential and are therefore considered non-special conditions.

3. Results

3.1. Embodied carbon emissions
Figure 1 shows the embodied carbon emissions of the 51 collected cases. The EC varies between 4.34 and 15.22 kg CO_2e/m^2/year which shows a great variation between the buildings. The median value is

7.96 kg CO_2e/m^2/year. No evident trend in carbon emissions can be observed among the different building typologies. Among the 51 cases, the embodied carbon emissions of 32 are higher than the median of conventional Danish buildings (7.3 kg CO_2e/m^2/year). However, this does not necessarily indicate that the buildings are affected by special conditions. The ones potentially affected by special conditions are further discussed with the respective stakeholders to identify the actual special conditions.

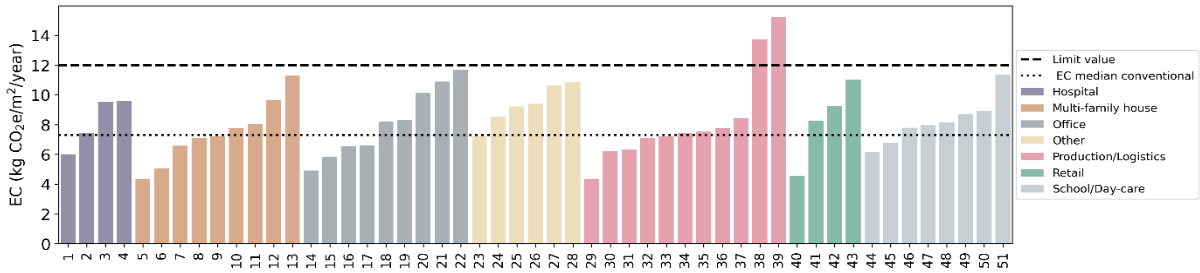

Figure 1. Embodied carbon emissions of the 51 case buildings in kg CO_2e/m^2/year. The dashed line represents the valid limit value, the dotted line represents the EC median of conventional buildings[5].

3.2. Identified special conditions

3.2.1. Buildings with hospital- and laboratory equipment
The need for the correct functionality of hospital and laboratory equipment can require specific requirements for load-bearing constructions. This can be due to vibration-prone equipment, x-rays, and corpuscular radiation from linear accelerators. These requirements can include, for example, double-constructed walls or massive bottom plates.

3.2.2. Buildings with high payload on the ground floor slab
In buildings where heavy transportation occurs or where heavy equipment such as process equipment or similar items must be placed within the building envelope, it can necessitate the design of ground floor slabs with a high load-bearing capacity. The need for a high payload occurs due to the required function of the building.

3.2.3. Buildings designed in consequence class CC3+
The failure of load-bearing structures in buildings that can result in the loss of human lives or have significant economic, environmental, or social consequences, may necessitate the implementation of load-bearing structures in accordance with consequence class CC3+ (cf. DS/EN1990). These are buildings with >15 floors, hospitals with >5 floors, or buildings with wide spans for theatres, museums, sports facilities, or concerts. The quantity of building materials is not directly dependent on the CC3+ classification; however, potential significant deformations, fractures, or dynamics of the load-bearing structures can lead to the need for larger cross-sectional dimensions. If an increase in the ultimate load can be documented, resulting in the need to design the load-bearing structures according to ultimate load strength, this can be considered a special condition.

3.2.4. Buildings with challenging soil conditions
Requirements for building foundations may be necessary for buildings constructed in buildings constructed on soils such as tertiary plastic clay near the ground surface or on inclinations. These requirements can lead to the need for additional construction materials and, consequently, result in additional carbon emissions that cannot be minimized without altering the building's function Excessive groundwater levels can also lead to increased material usage and associated carbon emissions. The function of the building decides whether soil conditions can be considered special conditions. This means that soil conditions are not considered special conditions unless it can be demonstrated that the functionality of the building is directly influenced by the specific plot. However, if the building is constructed on problematic soil, the above-ground structure should be optimized to

the fullest extent possible to compensate for any foundation or basement issues before considering the soil as a special condition.

3.2.5. Buildings with severe hygiene requirements
In buildings such as hospitals, labs, or production facilities, hygiene requirements can necessitate the use of specific materials, such as epoxy, as surface treatments on walls, ceilings, and flooring. In these cases, the surface treatment can lead to higher carbon emissions compared to treatments in residential and office buildings. Since these materials are necessary for the operations within the building, hygiene requirements can be considered special conditions.

3.2.6. Buildings with severe security requirements
Severe security requirements, such as those found in museums or prison buildings, can lead to the utilization of additional high-carbon materials, resulting in increased carbon emissions in the buildings.

3.3. Identified non-special conditions

3.3.1. Architectural design choices
Architectural design choices, such as cladding on the facade, balconies, and corbels, contribute to carbon emissions but do not serve critical functions in the building. Therefore, if architectural design choices result in increased carbon emissions and the building fails to comply with the limit value, optimization should be implemented in other areas of the building.

3.3.2. Buildings with large room volumes
Buildings with large volumes and optimized frame structures, but without significant numbers of room separations, were found to not face challenges in complying with the limit value. Participants in the study noted that such buildings typically have a large building envelope in relation to the floor area, with a limited number of large rooms and minimal horizontal and vertical room separators. This observation was specifically mentioned in relation to warehouses, sports halls, or logistic facilities. Although the building envelope includes the heaviest building elements and contributes significantly to the embodied carbon impact, the overall impact does not pose a problem in meeting the compliance value.

3.3.3. Buildings with basements
The impact of construction basements was examined by analyzing six case buildings with and without the inclusion of the basement construction. The study revealed that the embodied carbon emissions for the buildings varied between -5% to +5% when the emissions from the basements were not taken into account.

3.3.4. Buildings with many room separations
Many room separations can increase the quantity of materials per square meter and the associated carbon emissions, e.g., in dorm buildings or hotels. However, the high utilization of materials per sqm is often due to a lack of material optimizations. Thus, the need for many room separations is not a special condition since there is optimization potential in the amount of material utilized.

3.4. Calculation model for additional carbon emissions
A simple calculation model is proposed to handle additional carbon emissions from special conditions in building regulations. The final calculation model must encourage the identification of optimization and reduction potentials in both resource use and carbon emissions. The model should calculate the permitted additional carbon emissions that occur due to special conditions; however, it should only be applied when necessary. This means that the model should be used after all possible optimizations have been achieved, and further optimization is not possible without altering the required functions of the building. Therefore, the model should be defined to consider only the problematic areas of the building. The benchmark value can either be a reference value or an archetype. In the case of the reference value, it can be based on actual buildings, and the sample size can be expanded over time. Additionally, several building typologies can be collected, and reference values can be differentiated between typologies.

Archetypes can also be defined and made available in the LCA software, but the choice of archetype would be subjective, and wrong assumptions can be made.

3.4.1. Final model
The finalized method only considers areas of the building that are challenged by special conditions, thus isolating the problematic areas from the rest of the building. The additional carbon emissions (AC) are found specifically for the quantity of materials in building constructions that are specially conditioned and that can lead to non-compliance with the limit value. For instance, only specific areas of the building slabs with high payload are considered, and not the entire ground floor slab. The calculation model is presented below.

$$AC = \frac{X/RSP \ - R \cdot m}{GFA} > 0 \ [kg\ CO_2e/m^2/year] \ (1)$$

For columns and beams a stand-alone formula is developed, which is:

$$AC = \frac{R \cdot m}{GFA} \ [kg\ CO_2e/m^2/year] \ (2)$$

Where X is the carbon emissions of the specific building construction affected by special conditions (kg CO_2e), RSP is the reference study period (50 years in Denmark), R is the reference value of the specific building construction type (given in Table 1), m is the quantity of the building construction affected by special conditions (m^2 or m), and GFA is the gross floor area of the building (m^2). The reference value in Formula 1 is subtracted to find the difference. The difference is considered as the additional carbon embodied emission that the limit value can be exceeded with. If the result of the formula is less than zero, the carbon emission of the specific building structure is within the reference value thus the model cannot be applied, and no additional carbon emissions can be achieved or permitted. It is recommended that the additional carbon emission should be limited to ensure the basis for optimising the embodied carbon emissions.

Table 1. Reference values of structures to calculate additional carbon emission due to special conditions.

Structure	**Unit**	**Reference value (R)**
Floor slab	kg CO_2e/m^2 structure/year	1.30
Flooring	kg CO_2e/m^2 structure/year	0.65
Ceiling	kg CO_2e/m^2 structure/year	0.45
Internal walls	kg CO_2e/m^2 structure/year	1.03
Roof	kg CO_2e/m^2 structure/year	3.00
Ground floor slab/slab foundation	kg CO_2e/m^2 structure/year	2.27
External walls	kg CO_2e/m^2 structure/year	2.85
Columns and beams	kg CO_2e/m structure/year	0.47
Foundation	kg CO_2e/m^2 GFA/year	1.06

3.5. Example of how to apply calculation model
A fictional example is given to demonstrate how to use the calculation model and determine additional embodied carbon emissions by which the limit value can be exceeded.

A hospital building with a gross floor area of 3,000 m^2 and a linear accelerator must be built with massive internal walls and ground floor slab, which results in additional use of materials and exceeding the limit value of 12 kg CO_2e/m^2/year. The additional embodied carbon of the ground floor slab of 300 m^2, which emits 63,400 kg CO_2e, should be calculated as follows:

$$AC_{building} = \frac{63400 \frac{kg\ CO_2e}{50\ years} - 1.3\ kg\ CO_2e/m^2/year \ \cdot 300\ m^2}{3000\ m^2} = 0.29\ kg\ CO_2e/m^2/year$$

This means that the building would be permitted to emit an additional 0.29 kg CO_2e/m^2/year, thus emitting 12.29 kg CO_2e/m^2/year.

4. Discussion

The urgency of the climate crisis should be sole the motivational factor for the construction industry to find scalable optimisation and reduction potential of carbon emissions. Even though laws permit emitting additional carbon emissions for special conditions, the other parts of the building should be optimised in resource use and carbon emissions as much as possible to compensate for the areas of the building, that are affected by special conditions.

The calculation model defined in this study must not hinder the encouragement to optimise the environmental impacts of buildings. Optimizing is necessary to meet climate targets must. Therefore, industry professionals are strongly encouraged to only apply the model as a last resort for buildings when a special condition arises and when all possible optimization potentials have been thoroughly investigated and tested to address the challenges posed by the special condition.

The limit values of the Danish legislation are expected to be tightened in 2025, 2027, and 2029, which will undoubtedly compel the industry to seek additional reductions in carbon emissions. However, achieving this requires ambitious limit values that ensure substantial and necessary reductions. Legislation permitting further carbon emissions across all types of buildings should be reconsidered. Conventional residential and office buildings, which account for the largest share of new constructions, should not be allowed to emit additional carbon emissions. The permission should only apply to buildings that serve a vital and irreplaceable function in society, such as education, healthcare, culture, production, and so on.

5. Conclusion

This study investigated potential special conditions of buildings that can result in additional material use and related carbon emissions, posing challenges in complying with building regulations. Real examples of problematic building structures were examined to identify the parameters that can be classified as special conditions. Subsequently, a straightforward mathematical calculation model was developed to address the management of additional carbon emissions within building regulations.

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