ISSN 1831-9424

European Commission

Background report for the revision of EU Green Public Procurement criteria for Buildings

Ranea Palma, A., Gonzalez Torres, M., Perez Arribas, Z., Donatello, S.

2024

EUR 40095

Joint Research Centre

This document is a publication by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The contents of this publication do not necessarily reflect the position or opinion of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

This document is the background report for the revision of the Green Public Procurement (GPP), which began in 2020. It has taken into consideration the legislative framework and draft proposals of the regulation under revision by the time of elaboration of the criteria. However, it is important to understand that this report is not going to be updated once the regulation comes into force.
In any case, this publication is valuable as it represents an extensive and significant research effort that supports the proposed set of criteria. The insights and findings presented herein offer a robust foundation for understanding and implementing sustainable building practices, even in the context of forthcoming regulatory changes.

Contact information
Name: Ángela Ranea Palma
Email: Angela.RANEA-PALMA@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC138891

EUR 40095

PDF ISBN 978-92-68-21586-9 ISSN 1831-9424 doi:10.2760/3484975 KJ-01-24-117-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Centre, Ranea Palma, A., Gonzalez Torres, M., Perez Arribas, Z. and Donatello, S., *Background report for the revision of EU Green Public Procurement criteria for Buildings*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/3484975, JRC138891.

Contents

Abstract

Public administrations have a duty to promote sustainability policies and also to lead by example, serving as a reference point for the private sector and society in general, by committing to its fulfilment. In this sense, Green Public Procurement (GPP) criteria are a very valuable voluntary instrument, which allows the different institutions to use public money in an environmentally friendly way.

In 2020, the Commission initiated the revision of the EU GPP criteria for the building sector in an ambitious context, with the European Green Deal calling for a transition to a circular and sustainable economy, as well as a climate-neutral Europe. The building sector, due to its high environmental impact, is key to achieve a circular and sustainable economy, as well as the decarbonisation of Europe and should not miss the opportunity to design buildings with less impact over their life cycle.

The aim of this revision is to update the criteria for office buildings and to expand the scope to also include educational buildings and social housing. The process has kept into consideration the coherence with existing and upcoming legislation and policy tools, bearing in mind the alignment with Level(s). This report is intended to provide the background information for the revision of the EU GPP criteria for buildings. Market and technical analyses of current trends show significant room for improvement, especially in terms of reskilling the sector, increasing awareness and reducing environmental impact by promoting passive features, renewable sources, circularity and occupants' conservative behaviours. In light of the already observable effects of climate change on the environment and how it affects the buildings in which we live and work, designing for adaptation to extreme weather events becomes a must.

The set of EU GPP criteria proposals aim to consider the European context which is highly diverse in terms of building practices, encompassing climate, culture, social and economic factors. It strives to be ambitious, versatile, easy to implement and simple in its application. Moreover, the synergies between the different criteria make this voluntary instrument an even more powerful weapon to make the building sector more sustainable, of course taking into account the necessary trade-offs.

Acknowledgements

This report has been developed in the context of the Administrative Arrangement between DG Environment (ENV) and the Joint Research Centre (JRC).

The authors wish to thank the co-ordinating policy officer from DG Environment and other Commission colleagues for their valuable discussions, inputs and reactions to the report. The authors also thank Anna Atkinson (JRC.B5) for proofreading this document.

Finally the authors also thank all the stakeholders who have participated in the criteria revision process and contributed valuable insights and experiences that have helped shape these criteria proposals.

Authors

Ranea Palma, A., Gonzalez Torres, M., Perez Arribas, Z., Donatello, S.

Executive summary

Public administrations have a duty to promote sustainability policies and also to lead by example, serving as a reference point for the private sector and society in general, by committing to its fulfilment. In this sense, Green Public Procurement (GPP) criteria are a very valuable voluntary instrument, which allows the different institutions to use public money in an environmentally friendly way.

In 2016, the Commission published the EU GPP criteria for the construction sector given the huge impact these activities were having on the environment. In 2020, the Commission initiated a review of the criteria applied to this sector, in an ambitious context, with the European Green Deal calling for a transition to a circular and sustainable economy, as well as a climate-neutral Europe. Currently and considering the whole life cycle of a building, the European building industry is responsible for almost half of Europe's energy and material consumption and one third of water consumption, waste generation and greenhouse gas emissions. Thus, the construction sector is a key player to help Europe achieve climate neutrality by 2050, ensuring the success of this challenge.

A significant part of the legislation affecting the construction sector has had to be reviewed. The most relevant examples include the Energy Performance for Buildings Directive, the Energy Efficiency Directive, the Construction Product Regulation and the Waste Framework Directive. New instruments have also been launched, such as the EU Taxonomy, the New European Bauhaus or the Renovation Wave for Europe. The European Green Deal and its entire development framework draw a scenario of a new decarbonised and more circular Europe which is a motivation for designing new criteria for the building sector. On the one hand, the Green Deal sets out a fairly clear roadmap for the short and medium term, so there is a fairly strong trend, but on the other hand, this leads to an intensive review of policies affecting the sector. In order to facilitate the application and coherence of the criteria and their alignment with the regulatory framework under revision, the legislative proposals have been thoroughly analysed, discussed extensively with stakeholders and checked against the state of the art to ensure that they do not quickly become outdated. Consequently, the definition of the new criteria has required an even greater effort.

In this context, the aim of this revision is to update the criteria for office buildings and to expand the scope to also include educational buildings and social housing. The process has kept into consideration the coherence with existing and upcoming legislation and policy tools, bearing in mind the alignment with Level(s), the European framework for assessing and reporting on the sustainability performance of buildings. This report is intended to provide the background information for the revision of the EU GPP criteria for buildings. Thus, it will serve to identify key improvement opportunities for the different areas of the buildings where new EU GPP criteria can be developed, and examine the comprehensiveness and appropriateness of the existing ones.

In addition to the identification and summary of relevant policies and Green Building Rating Schemes, background research is provided on: (i) the EU building stock and key economic indicators of the building construction sector, (ii) a short review of the main environmental impacts associated with buildings and (iii) a technical analysis of the main topics under scope. This last point in particular is used to assess the potential for improvement in building performance and help to define ambitious but coherent EU GPP criteria.

Main findings

- There is a clear need for sustainability skills training for all actors involved in the life cycle of a building.
- The building design phase is a crucial stage in the decision making process which will lead to more circular, sustainable and adaptable buildings.
- The importance of adopting the definition of Zero Emission Buildings, since this concept combines energy performance with the use of renewable energy to supply the reduced energy demand, ensuring the synergy between energy efficiency and reduced carbon emissions.

- The urgency of applying the principle of prevention to energy efficiency and thermal comfort strategies in buildings, considering non-consumption as a priority. Thus, the first step in the hierarchy of actions would be to include appropriate passive measures in the design, before considering mechanical heating and cooling systems.
- The lack of circular economy thinking in the design stage, which would extend the life cycle of the buildings, using systems to be easily maintained, repaired and replaced, and would furthermore support the reduction of whole life carbon.
- The opportunity to push for a high quality of recycling, when refurbishing buildings or when they reach their end of life stage, in order to promote the recycled materials market.
- The added value of including grey water reuse and rainwater harvesting strategies to reduce water consumption from the grid.
- The relevance of incorporating the comfort and well-being of occupants, including accessibility aspects, as a crucial element when designing or renovating a building.
- The lack of assessment of the climatic risks to which a building will be subjected and therefore the consideration of resilience as a determining element to extend its life and increase its value.
- The importance of considering the economic variable both in terms of the possible costs that different decisions about the building might entail and the income that would allow the investment to be recovered, or actions that would increase its value or its useful life span.
- The lack of applicability of biodiversity preservation strategies and widely recognised chain of custody standards for many materials used in construction.

As a result, the EU GPP criteria for buildings will be centred on the following seven themes:

- Energy consumption and life cycle greenhouse gas emissions
- Material efficiency and circularity
- Efficient use of water resources
- Occupant comfort and wellbeing
- Vulnerability and resilience to climate hazards
- Life Cycle Costing
- Biodiversity

It should be noted that the process of revising the criteria has incorporated two new themes that are crucial for the sustainability of buildings: Vulnerability and resilience to climate hazards and Biodiversity. Moreover the criteria set belonging the rest of the themes has been deeply revised and enriched.

The criteria have been conceived as a broad and detailed set of measures from which to choose the most appropriate ones to adapt, both to the project to be developed by the contracting authority and to the local reality in which it is carried out. To be a success, EU GPP needs clear, up-to-date and verifiable environmental criteria.

The idea is to provide a proposal of solutions that individually or jointly ensure the sustainability of the building, whether a new construction or refurbishment. In this way, prescription has been avoided as far as possible, opting for flexible solutions that allow the achievement of the desired objective. For this reason, it has always been borne in mind that different social, cultural, economic and climatic realities coexist in the EU.

In order to facilitate the application and verification of the criteria, simplicity has been sought in the application and considerable effort has been made to provide templates that can serve as a guide and that also intend to bring transparency and coherence.

The selection criteria (SC) have been used as a vehicle to raise awareness in the sector and promote greater skills in the field of sustainability among the actors involved. Likewise, the comprehensive level of ambition as well as the award criteria have been crucial to reward those projects conceived with a more demanding circular approach.

Due to the high environmental impact of the building sector in terms of energy, emissions, water and material consumption, designing buildings in a sustainable way is key to achieving European climate targets. This has required an even greater effort to find the right balance between simplicity in implementation of the criteria and maintaining the level of ambition.

Key conclusions

- The potential impact of EU GPP criteria could be increased by a factor of four by expanding the scope to include educational buildings and social housing in addition to public offices.
- The EU GPP criteria should be versatile, easy to implement, and simple in its application to adapt to a European context that is highly diverse in terms of building practices, encompassing climate, culture, social, and economic factors.
- Market and technical analyses of current trends show significant room for improvement, especially in terms of reskilling the sector, increasing awareness and reducing environmental impact by promoting passive features, renewable sources, circularity and conservative occupants behaviour.
- The design phase is crucial to conceive the building based on circular thinking.
- In light of the already observable effects of climate change and how they affect the buildings in which we live and work, designing for adaptation to extreme weather events becomes a must.
- The use of the criteria by taking advantage of their synergies and balancing the different trade-offs increases their positive impact on the building.

Related and future research work

The possible future lines of work that this research work has revealed are as follows:

- The potential of the ZEB concept as a standardised reference to compare the environmental performance of buildings, once the national thresholds and definitions are stablished.
- Passive construction techniques and their impact on the energy efficiency of a building.
- Aspects to upgrade for fostering high-quality recycling. Results of existing strategies and tools and improvement options.
- Innovative systems for recovering water that improve well-being and comfort and foster biodiversity, considering a climate change scenario.
- The impact of sustainability on the value of a building throughout its life cycle. Links between low whole life carbon, circular, resilient and cost-effective buildings.

1. Introduction

The EU Green Public Procurement (GPP) policy is a voluntary instrument to encourage and assist Europe's public authorities to use their purchasing power to drive the adoption of environmentally friendly goods, services and works to make an important contribution to sustainable consumption and production. It can help stimulate the demand for more sustainable goods and services which otherwise would be difficult to get onto the market. It is therefore a way of leading by example and a strong stimulus for eco-innovation.

To be a success, EU GPP needs clear, up-to-date and verifiable environmental criteria. This report is intended to provide the background information for the revision of the EU GPP criteria for buildings. Thus, it will serve to identify key improvement opportunities for the different areas of the buildings where new EU GPP criteria can be developed, and examine the comprehensiveness and appropriateness of the existing ones. Given the exceptional situation in which the project preparation has taken place coinciding with the in-depth revision of the related legislative framework, this report has been updated as necessary at later stages and in parallel to the preparation of the technical report, in order to provide the most comprehensive picture.

The report consists of: a background section which introduces the report and summarises the cross-sectorial and buildings-related policies in Europe and describes the criteria development and stakeholder consultation process; an analysis of the scope, definitions and description of the legal framework (Task 1); a market analysis (Task 2); an overview of existing lifecycle assessment and non-lifecycle assessment studies, revealing the significant environmental impacts (Task 3); and a technical analysis to identify the improvement potential (Task 4). Combined with input from stakeholders, this information has been used to develop and revise the set of criteria (Technical Report, Task 5).

Since the publication of the EU GPP criteria for office buildings in 2016, many policy developments that have an influence on the revision of this EU GPP criteria set have taken place. In this chapter, some key, cross-cutting and high-level policies in Europe are highlighted before entering into details of those purely focused on buildings. Then, the criteria development and stakeholder consultation process is described.

High-level, cross-sectorial policy context

The European Green Deal

As set out in Communication (2019) 640[1], the European Green Deal (EGD) is the Commission's new growth strategy to transform the EU into a fair and prosperous society. This has been structured into 11 key elements, which are illustrated below.

[1] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. Brussels, 11.12.2019 (COM(2019) 640 final). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640

Figure 1. The European Green Deal (EGD)

Source: author's own elaboration.

From the 11 key elements of the European Green Deal, EU GPP criteria for buildings can be considered to have the following degrees of relevance and potential influence:

- "Building and renovating in an energy and resource efficient way": complete relevance and direct linkage to potential EU GPP criteria for buildings by looking at their whole life carbon and energy performance, design for adaptability and deconstruction, and management of Construction and Demolition Waste (CDW).
- "Increasing the EU's Climate ambition for 2030 and 2050": directly relevant to buildings in terms of operational CO_2 emissions from energy consumption in buildings and embodied CO_2 in construction products, materials and waste.
- "Supplying clean, affordable and secure energy": partially relevant and direct linkage to potential EU GPP criteria if referring to renewable energy installed in-situ or nearby, including district heating.
- "Preserving and restoring ecosystems and biodiversity": partially relevant and indirect linkage to EU GPP criteria if referring to green roofs or green walls.
- "A zero pollution ambition for a toxic-free environment": partially relevant and indirect linkage to EU GPP criteria if referring to emissions of Volatile Organic Compounds, ventilation performance class and indoor supply air classes delivered by ventilation systems.
- "Financing the transition": EU GPP criteria, by their very nature, can act as a key instrument to specify the purchasing of goods or contracting of services that are in line with the goals of the EGD. The construction of new buildings and the renovation of existing ones, at the European level, involves considerable sums of money – thus representing a major opportunity for driving change.

This last point links to another cross-cutting and highly relevant policy, the EU Taxonomy.

The EU Taxonomy for sustainable economic activities

The aim of the taxonomy is to provide a common language and clear definition of what economic activities can be considered "environmentally sustainable". The taxonomy works within the existing classification of economic activities and sets rules for companies to report according to common rules and principles.

The taxonomy thus enables investors to better understand how environmentally sustainable the companies and activities they are investing in actually are. The taxonomy is focused on the following six environmental objectives:

1. Climate change mitigation
2. Climate change adaptation
3. The sustainable use and protection of water and marine resources
4. The transition to a circular economy
5. Pollution prevention and control
6. The protection and restoration of biodiversity and ecosystems

The basic framework for the EU Taxonomy is set out in Regulation (EU) 2020/852[2]. The framework makes general reference to the conditions that an economic activity must comply with in order to be considered environmentally sustainable. Specific technical screening criteria for Substantial Contribution and Do No Significant Harm for relevant economic activities will be provided in a total of six Annexes to Regulation (EU) 2020/852, one per environmental objective.

For each Annex, criteria are set for economic activities that are considered to have the potential to make a significant contribution to the corresponding environmental objective. The contribution can be made in different ways, namely by a direct contribution based on the performance of the economic activity or an indirect contribution due to one economic activity enabling the direct contribution of another economic activity.

Annex I (on climate change mitigation) and Annex II (on climate change adaptation) of the Climate Delegated Act were published in June 2021. In June 2023, a new environmental delegated act was adopted to include a new set of EU taxonomy criteria for economic activities making a substantial contribution to one or more of the non-climate environmental objectives, namely: sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control and protection and restoration of biodiversity and ecosystems.

EU Taxonomy economic activities of direct relevance to the EU GPP criteria for buildings for the different environmental objectives are summarised below.

[2] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32020R0852

Table 1. Cross-check of building-related economic activities in the EU Taxonomy against environmental objectives[3]

Economic activity (within the construction and real estate sector)	**1. Climate change mitigation**	**2. Climate change adaptation**	**3. Water and marine resources**	**4. Circular economy**	**5. Pollution prevention and control**	**6. Biodiversity**
The construction of new buildings	X	X		X	X	X
The renovation of existing buildings	X	X		X	X	X
The installation, maintenance and repair of energy efficiency equipment	X	X		X	X	
The installation, maintenance and repair of charging stations for electric vehicles in buildings (and parking spaces attached to buildings)	X	X		X		X
The installation, maintenance and repair of instruments and devices for measuring, regulation and controlling energy performance of buildings	X	X		X	X	
The installation, maintenance and repair of renewable energy technologies	X	X		X		X
The acquisition and ownership of buildings	X	X			X	

Source: author's own elaboration.

It is clear that the EU Taxonomy covers potential procurement criteria for buildings in both a broad sense (i.e. new construction activity, renovation activity and acquisition activity) and in more focused activities (e.g. energy efficiency equipment or on-site renewable energy technologies).

Circular Economy Action Plan

The shift to a circular economy is regarded as an opportunity to establish new job-intensive activities within Europe's industry and bring more manufacturing back to the EU in some sectors, while minimising environmental and climate impacts. The EU Circular Economy Action Plan 1.0 from 2015[4] required changes to EU legislation to encourage a more circular economy.

This included amendments to the Waste Framework Directive, which makes several additional references to Construction and Demolition Waste (CDW). Some of the most relevant updates in the revised Waste Framework Directive for CDW are as follows:

- Article 3: Setting a definition of CDW.
- Article 9(d): To encourage the re-use of and repair of construction materials and products.
- Article 9(f): To take into account best available techniques to reduce CDW generation.
- Article 11(b): To promote selective demolition for the removal and safe handling of hazardous CDW.

[3] Note that only the cells coloured in green are subject of adopted delegated acts by the time of the elaboration of this publication. The other identified topics could be subject of future work.

[4] Communication from the Commission to the European parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop - An EU action plan for the Circular Economy, Brussels 2.12.2015 (COM(2015) 614 final). Available at: hhttps://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614

- Article 11b): To establish sorting systems for CDW at least for wood, mineral fractions, metal, glass, plastic and plaster
- Article 11(6): To consider, by 31 December 2024, the setting of preparing for reuse and recycling targets for CDW and its specific material fractions.

In March 2020, the European Commission introduced a new Circular Economy Action Plan (CEAP) as one of the key elements of the European Green Deal. The aim of the second CEAP is to reduce the EU's consumption footprint and double the EU's circular material use rate in the coming decade, while boosting economic growth.

Construction and buildings are highlighted as one of the key product value chains in the new CEAP – with construction and demolition activities being considered responsible for around 35% of all EU waste generated. The CEAP highlights key principles to be applied to buildings, such as design for durability, design for adaptability and material and resource efficiency. The safe, sustainable and circular use of excavated soils is specifically mentioned, as are initiatives to reduce soil sealing and to consider revising CDW material recovery targets.

In addition, the Commission adopted the revised EU monitoring framework on the circular economy in May 2023. Among other interesting metrics on production and consumption, waste management, secondary raw materials, competitiveness and innovation and global sustainability and resilience indicators, it includes an indicator that measures the share of public procurement procedures above the EU thresholds (in number and value), which include environmental elements, acknowledging the key role that public procurement can play in the circular economy. It will become available in 2024 with reference year 2023.

Recovery Plan for Europe

The announcement of the COVID-19 pandemic and the ensuing lockdowns and restrictions implemented by governments across the EU have had severe economic consequences. In an effort to repair and recover from these impacts, the EU has agreed to create "Next Generation EU"[5], which also forms part of the new long-term EU budget for 2021 to 2027.

The Next Generation EU programme effectively borrows EUR 750 billion from financial markets, which will be repaid over a long period of time in future EU budgets (not before 2028 or after 2058). The majority of this new finance (EUR 560 billion) is being attributed to what is termed the "Recovery and Resilience Facility", whose aim is to support investments and reforms to deliver green and digital transitions that improve the resilience of national economies in a way that also links to EU priorities.

Member States were required to draw up national recovery and resilience plans and a recurring theme in many of them was the renovation of building stock to improve energy efficiency. Renovating existing building stock has clear resource efficiency benefits compared to demolishing and building new, and improving energy performance can help societies move towards climate neutrality whilst also limiting the risk of energy poverty. To maximise the benefits of such investments, it is important to make sure that investments are targeted to the most vulnerable members of society and to the buildings where the most cost-effective improvements can be made.

[5] Recovery plan for Europe: Next Generation EU. Available at: https://commission.europa.eu/strategy-and-policy/recovery-plan-europe_en#nextgenerationeu

Energy Efficiency Directive

The 2012 Directive No (EU) 2012/27[6] sets rules and obligations for achieving the EU's energy efficiency targets. The EU's 2020 targets on final and primary energy consumption were both surpassed and the Directive was amended in 2018 (2018/2002/EU)[7] to update the policy framework to 2030 and beyond.

Under the Directive, EU countries have to set indicative national contributions, using a combination of objective criteria, which reflect national circumstances (energy intensity, GDP per capita, energy savings potential and fixed energy consumption reduction). Member States are required to draw up integrated 10-year National Energy and Climate Plans (NECPs) outlining how they intend to meet the energy efficiency and other targets for 2030.

To step up efforts, the Commission proposed a second revision of the EU Energy Efficiency Directive as part of the Fit for 55 package[8] and adopted it in July 2023[9]. Its main goal is to reduce final energy consumption at EU level by 11.7% in 2030, compared to projections made in 2020.

The proposed rules put forward several provisions to accelerate energy efficiency efforts by Member States, such as increased annual energy savings obligations and new rules aimed at decreasing the energy consumption of public sector buildings. A significant advancement is the introduction of an annual energy consumption reduction target of 1.9% for the public sector as a whole. Moreover, the annual 3% buildings renovation obligation is being extended to all levels of public administration. The public sector will also play a driving role in the development of the energy services market. Energy Performance Contracts will be prioritised in the implementation of energy efficiency projects in the public sector, whenever possible. Public bodies will continue to consider energy efficiency requirements when making decisions regarding the purchase of products, buildings, and services, fostering systematic improvements. Moreover, it mentions contracting authorities as important actors that can take action as part of procurement procedures by purchasing new buildings that address global warming potential over the full life cycle. Thus, it is directly linked to EU GPP criteria for buildings.

Renewable Energy Directive

The Renewable Energy Directive (RED) is the legal framework for the development of clean energy across all sectors of the EU economy. Since its introduction (2009/28/EC)[10], the share of renewable energy sources in EU energy consumption has increased from 12.5% in 2010 to 23% in 2022.

Being highlighted under the European Green Deal as a pillar of the clean energy transition and given the need to accelerate it, the RED was last revised in 2023, resulting in the amending Directive EU/2023/2413[11].

[6] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027

[7] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.328.01.0210.01.ENG

[8] Fit for 55 - The EU's plan for a green transition. Available at: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

[9] Proposal for a Directive of the European parliament and of the Council on energy efficiency (recast) (COM/2021/558 final). Available at: https://www.europarl.europa.eu/doceo/document/TA-9-2023-0068_EN.html#title1

[10] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Not longer in force. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028

[11] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105

The revised directive introduces stronger measures to ensure that all possibilities for the further development and uptake of renewables are fully utilised and to target to double the existing share of renewable energy sources. Moreover, a strong policy framework is set to facilitate electrification in different sectors, with new increased sector-specific targets for renewables in heating and cooling, transport, industry, as well as in buildings (article 15a).

Building-specific policy

This section summarises the policy context that addresses the building sector as a whole. For the relevant policy, legislation and standards that are specific to each of the Themes in which the EU GPP criteria for buildings are structured, there is an independent section within Task 1 below.

Renovation Wave

In October 2020, the European Commission published a communication titled: "A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives"[12]. The need for such a strategy is underpinned by the relatively old age of Europe's building stock (with 85% of existing buildings today being more than 20 years old) and the fact that around 85% to 95% of buildings existing today will still be there in 2050. Consequently, there is (i) significant room for improvement in existing building stock and (ii) to meet any climate neutrality or building energy efficiency targets in 2050, renovation of existing building stock will play a major role.

The current rate of energy renovation in buildings is very low (around 1%, and just 0.2% for "deep" energy renovations). The EU strategy aims to double annual energy renovation rates in the next 10 years with a particular focus on:

- tackling energy poverty and the worst-performing buildings;
- public buildings and social infrastructure;
- decarbonising heating and cooling.

The first bullet point in particular makes a direct link to the need to deliver improved building energy performance via GPP for new and renovated buildings. The Renovation Wave initiative aims to build upon national long-term climate strategies[13] and National Energy and Climate Plans[14] as well as dovetailing with Energy Performance Certificates (EPCs) and reporting under the Level(s) framework. Some of the key Renovation Wave actions are listed below.

Table 2. Key actions related to the Renovation Wave

Strengthening information, legal certainty and incentives for renovation	
Revision of Energy Performance Certificates and proposal to introduce mandatory minimum energy performance standards for all types of buildings in the EPBD	2021
Revision of requirements on energy audits in the EED	2021
Proposal on Building Renovation Passports and introduction of a single digital tool unifying them with Digital Building Logbooks	2023

[12] Communication from the Commission to the European parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, Brussels 14.10.2020 (COM(2020) 662 final). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[13] National long-term climate strategies. Available at: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-long-term-strategies_en

[14] National energy and climate plans. Available at: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en

Developing a 2050 whole life-cycle performance roadmap to reduce carbon emissions form buildings and advancing national benchmarking with Member States	2023
Reinforced, accessible and more targeted funding supported by technical assistance	2021
Proposed strengthened financing for the ELENA facility from the InvestEU advisory hub and possibly from other European programmes	
Consider the introduction of a 'deep renovation' standard as part of the EPBD revision	2021
Revising the climate-proofing guidelines for projects supported by the EU	2021
Supporting de-risking energy efficiency investments, and proposing to incorporate environmental, social and governance (ESG) risks into the Capital Requirements law and the Solvency II Directive	2021
Reviewing the General Block Exemption Regulation and Energy and Environmental Aid Guidelines	2021
Creating green jobs, upskilling workers and attracting new talent	
Supporting Member States to update their national roadmaps for the training of the construction workforce through the Build Up Skills Initiative and helping implement the 2020 European Skills Agenda	2020
Sustainable built environment	
Reviewing material recovery targets and supporting the internal market for secondary raw materials	2024
Presenting a unified EU Framework for digital permitting and recommending Building Information Modelling in public procurement	2021
Supporting digitalisation in the construction sector through Horizon Europe, Digital Innovation Hubs and Testing and Experimentation Facilities	2021
Placing an integrated participatory and neighbourhood-based approach at the heart of renovation	
Setting up a creative European Bauhaus platform to combine sustainability with art and design	2020
Supporting sustainable and decarbonised energy solutions through Horizon Europe and the R&I co-creation space	2020
Facilitating the development of energy communities and local action through the European Smart Cities Marketplace	2020
Supporting the development of climate-resilient building standards	2020
Tackling energy poverty and worst-performing buildings	
Launching the Affordable Housing Initiative piloting 100 renovation districts	2021
Public buildings and social infrastructure showing the way	
Proposing to extend the requirements for renovation to buildings in the EED to all public administration levels	2021
Based on Level(s), developing green public procurement criteria related to life cycle and climate resilience for certain public buildings	2022
Decarbonising heating and cooling	
Developing ecodesign and energy labelling measures	2020
Assessing the extension of the use of emission trading to emissions from buildings	2021
Revising the RED and the EED and considering strengthening the renewable heating and cooling target and introducing a requirement for minimum proportions of renewable energy in buildings. Also facilitating access of waste and renewable heat and cool into energy systems	2021

Source: author's own elaboration.

Clearly there are many ongoing policy actions relating to the Renovation Wave and this, coupled with the turmoil associated with the COVID restrictions and new recovery funding, means that more time may be needed to implement and assess progress in these action points.

The Level(s) framework

Level(s)[15] is a European framework for sustainability that aims to provide a common language for assessing and reporting on the sustainability performance of buildings. After testing a beta version of Level(s) in 80 different projects in 16 different countries, the first public version was published on the same day as the Renovation Wave initiative (14 October 2020).

While the framework has been developed very much with residential and office buildings in mind, it can be applied in principle to any type of building. It is built upon a series of 6 "macro-objectives" that cover different environmental, social and economic aspects of building performance:

1. Greenhouse gas and air pollutant emissions along a building's life cycle
2. Resource-efficient and circular material life cycles
3. Efficient use of water resources
4. Healthy and comfortable spaces
5. Adaptation and resilience to climate change
6. Optimised Life Cycle Cost and value

The first three macro-objectives are clear environmental goals, macro-objectives 4 and 5 have both social and environmental aspects while the last macro-objective is purely economic.

In order to seek standardisation and homogeneity, the use of the Level(s) indicators in the EU GPP criteria for buildings is recommended to promote such a common language for assessing and reporting on the sustainability performance of buildings.

New European Bauhaus

The New European Bauhaus[16] is a creative and interdisciplinary initiative that connects the European Green Deal to living spaces and experiences.

By creating bridges between different backgrounds, cutting across disciplines and building on participation at all levels, the New European Bauhaus inspires a movement to facilitate and steer the transformation of our societies along three inseparable values that should be present in EU GPP criteria for buildings:

- sustainability, from climate goals to circularity, zero pollution, and biodiversity;
- aesthetics, quality of experience and style beyond functionality;
- inclusion, from valuing diversity to securing accessibility and affordability.

The New European Bauhaus brings citizens, experts, businesses and institutions together to reimagine sustainable living in Europe and beyond. In addition to creating a platform for experimentation and connection, the initiative supports positive change by also providing access to EU funding for beautiful, sustainable and inclusive projects.

[15] Level(s). European framework for sustainable buildings. Available at: https://environment.ec.europa.eu/topics/circular-economy/levels_en
[16] Available at: https://new-european-bauhaus.europa.eu/get-involved/use-compass_en

Criteria development and stakeholder consultation process

Due to the high environmental impact of the building sector, designing buildings in a sustainable way is key to achieving European climate targets. This has required an even greater effort to find the right balance between simplicity in implementation of the EU GPP criteria for buildings and maintaining the level of ambition.

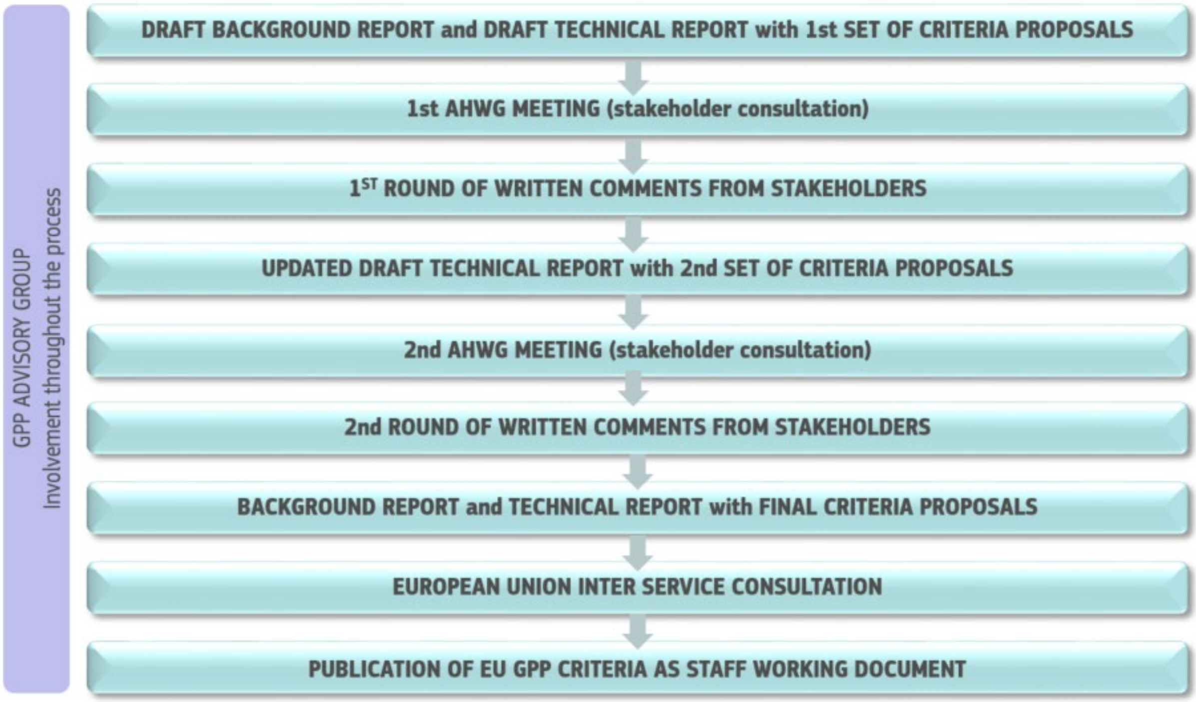
The criteria have been conceived as a broad set of measures from which to choose the most appropriate ones to adapt, both to the project to be developed by the contracting authority and to the local reality in which it is carried out.

The idea is to provide a proposal of solutions that individually or jointly ensure the sustainability of the building, whether a new construction or refurbishment. In this way, prescription has been avoided as much as possible, opting for flexible solutions that allow the achievement of the desired objective. For this reason, it has always been borne in mind that different social, cultural, economic and climatic realities coexist in the EU.

In order to facilitate the application and verification of the criteria, considerable effort has been made to provide templates that can serve as a guide and that also intend to bring transparency and coherence.

In order to update the EU GPP criteria for buildings, the Joint Research Centre (JRC) of the European Commission, together with DG Environment (ENV), conducted the necessary research and stakeholder consultation following the process illustrated below.

Figure 2. Illustration of the EU GPP criteria revision process



Source: author's own elaboration.

The process began with research being conducted by the JRC for the background report.

The first four tasks for the background report for buildings involve the following:

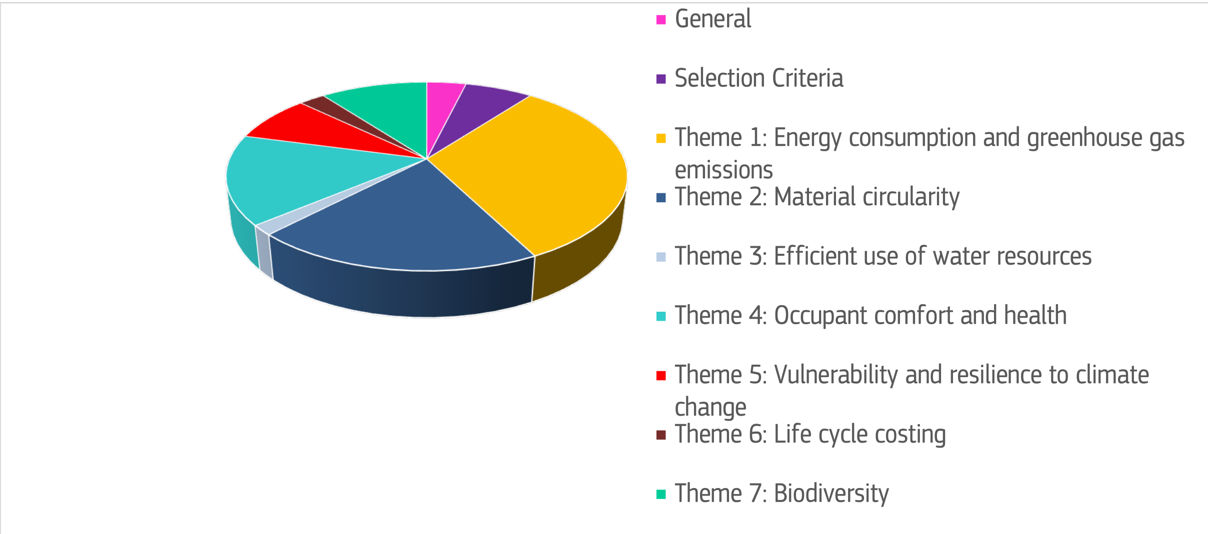
- **Task 1 (scope and definition)**: This task starts with the scope of the "product group", which in this case would refer to the types of buildings covered and the types of construction activity and building management that are covered. Depending on the scope, relevant definitions, policy, technical standards and legislation are identified.

- **Task 2 (market analysis)**: This task focuses on market analysis. In the case of buildings, there are many different types of service or activity that are relevant. Any interesting trends in the market should be flagged here – for example developments with Green Building Certification schemes.
- **Task 3 (main environmental impacts)**: The aim of this task is to identify the main environmental impacts associated with buildings. This process begins by reviewing relevant Life Cycle Assessments available in the literature so that environmental impacts and trade-offs can be identified across the entire building life cycle. However, it is also necessary to consider other environmental impacts that are not well captured by Life Cycle Assessment (LCA) methodologies, such as adverse effects on human health or biodiversity.
- **Task 4 (technical analysis and improvement potential)**: This task aims to assess the building from a technical perspective, looking at the different building elements, components, systems and controls that determine how a building functions and performs. Opportunities for improvement of particular systems or designs, and how they could reduce environmental impacts or bring other benefits, are explored in this task wherever possible.

All this was used to draw up the criteria proposals (task 5), which are presented in a separate, and more concise, technical report.

The content of the tasks 1 to 5 (especially the criteria proposals from task 5) were subjected to the 1st stakeholder consultation. Following reactions and input from stakeholders, a revised set of criteria proposals were produced and subjected to a second round of consultation. After the second meeting, a third stakeholder consultation for the EU GPP Buildings criteria was not considered, since no major issues were flagged that could realistically be resolved within an additional round of consultation.

Figure 3. Overall contribution from stakeholders to the two rounds of consultation



Source: author's own elaboration.

Figure 3 gathers the total number of written comments received in the two rounds of consultations that took place during the revision of the EU GPP criteria for Buildings.

At the second stakeholder meeting, an interactive platform was used in order to have an overall picture of the level of expertise among the audience per presented theme and to gather feedback on the spot that would enrich the discussion. Furthermore, it should be noted that the results of the survey back up the total number and relevance of comments received per theme which can be checked in detail in Annex II.

In Figure 3, it can be observed that the stakeholders showed great interest in Theme 1 on Energy consumption and greenhouse gas emissions, Theme 2 on Material circularity and Theme 4 on Occupant comfort and health as they are the most commented-on themes by far. This is in line with the active participation of stakeholders during the presentation of the aforementioned themes at the second ad-hoc working group meeting.

Regarding Theme 1, roughly half of the stakeholders who responded stated that they had some basic knowledge of Energy consumption and GHG emissions in buildings. The remaining responses were evenly distributed among those who were experts and those with some solid background knowledge. Only 3% of the respondents had no background knowledge. Additionally, the topics on whole Life Cycle Assessment, passive features and use-stage energy consumption were by far the most commented-on subthemes. This confirms the link between the level of expertise and the participation reached at the stakeholder consultations.

Concerning the second most commented-on theme, on material circularity, it could be observed that most of the attendees had a basic background knowledge. Most subthemes on material circularity raised equal interest among the stakeholders, particularly the one on design for adaptability while operational waste management was not commented on at all.

With respect to Theme 4, around half of the respondents had solid background knowledge of occupant comfort and well-being in buildings while the other half had at least some basic knowledge. This corresponds to the numerous written comments that were received, especially on ventilation performance and lighting levels, not only after the two rounds of stakeholder consultations but also during the ad-hoc working group meetings. These topics were specifically discussed on several occasions until a compromise was reached with the relevant experts.

Themes 5 and 7 received similar numbers of comments. In the case of Theme 5, most of the attendees who responded to the survey had a very basic or no background knowledge at all of vulnerability and resilience to climate change in buildings and perhaps that may be the reason why there were very few comments on this topic.

The least commented-on themes were notably Theme 3 on efficient use of water resources and Theme 6 on Life Cycle Costing. The lack of comments is in line with the low participation of experts on these topics during the criteria revision. In fact, at the second stakeholder meeting, almost half of the stakeholders who responded the Slido question on familiarity with the efficient use of water resources in buildings indicated that they only have some basic knowledge on the topic. Similarly, no written comments were received on the Life Cycle Costing requirements. Nonetheless, the number of respondents was quite low compared to those who responded to the questions of Themes 1 and 2.

Figure 4. General comments received on the overall EU GPP Buildings revision

Source: author's own elaboration.

The stakeholders commented mostly on the scope and the necessity for a more flexible application of the EU GPP criteria. (Figure 4). The importance of ensuring alignment of the criteria with the EU policy framework was highlighted several times as well by the stakeholders not only through written comments but also at the ad-hoc working group meetings.

Figure 5. Stakeholder comments on the selection criteria addressing the skills of actors involved in EU GPP for buildings

Source: author's own elaboration.

Figure 5 captures the stakeholders' written comments on the selection criteria addressing the skills of actors involved in EU GPP for buildings. Most of the stakeholders focused on the selection skills needed for the design team. However, many comments also highlighted the overall need for reskilling the building sector in sustainability aspects. Consensus was reached on the main constructor being the actor who most needs to be upskilled in this matter.

2. Task 1: Scope and definition

The scope of the EU GPP criteria for buildings can be considered in terms of:

- building functionality (i.e. the main purpose of the building, which could be residential, office, educational, commercial activity, industrial activity, civic buildings, sports-related buildings, social services, healthcare, religious, emergency services, military or combinations of these);
- building typology (e.g. prefabricated buildings, high-rise buildings, apartment blocks, detached houses, semi-detached houses, terraced houses, warehouses etc.; further distinctions may be made based on the choice of structural materials or other factors);
- economic activities related to the physical building asset (e.g. architectural services, engineering design services, demolition activities, site preparation works, construction works, renovation works, installation works, building management services, maintenance works, etc.);
- time (i.e. of the project and of the building lifecycle, from design, through construction, completion, occupancy and end of life);
- physical boundaries (i.e. whether to include the surrounding land on the building plot area, any parking areas and any installed energy systems that are not physically inside the building).

<u>Comparison to existing scope</u>

As will be shown later in the market analysis section, public office buildings generally count for less than 15% of the non-residential building floor area. Considering that the EU average floor area split between residential and non-residential buildings is 75% to 25%, this means that around 3% to 4% of the total EU building area is public offices. In order to increase the potential impact of EU GPP criteria for buildings, it was considered relevant to expand the scope to educational buildings and to social housing. Making the approximate assumptions from the task 2 data presented later, expanding the scope would increase the coverage of EU GPP criteria from around 3-4% of EU building floor area to around 11-12%, since around 20% of non-residential buildings are educational buildings (mostly public) and around 5% of all residential building floor area is social housing.

A comparison of the scope of the proposed EU GPP criteria for buildings and the previous criteria for office buildings[17] is provided below.

Table 3. Comparison of scope of proposed EU GPP criteria for buildings with those from 2016

	Proposed scope	2016 criteria
Building functionality	Office, residential and educational	Office
Building typology	Not specified	Not specified
Economic activity	Same	(i) preliminary scoping and feasibility; (ii) detailed design and applications for permits; (iii) strip-out, demolition and site preparation works; (iv) construction or major renovation works; (v) installation of energy systems and supply of energy services; (vi) completion and handover; (vii) facilities management and (viii) post-occupancy evaluation

[17] EU GPP Criteria for Office Building Design, Construction and Management. Available here: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/862af61d-a410-4baa-a7b9-22273623db57/details

Time	From design up until end of life	From design up until end of occupancy
Physical boundary	Includes parking and areas beyond building curtilage but still within building plot area	Does not cover parking and areas beyond building curtilage but still within building plot area

Source: author's own elaboration.

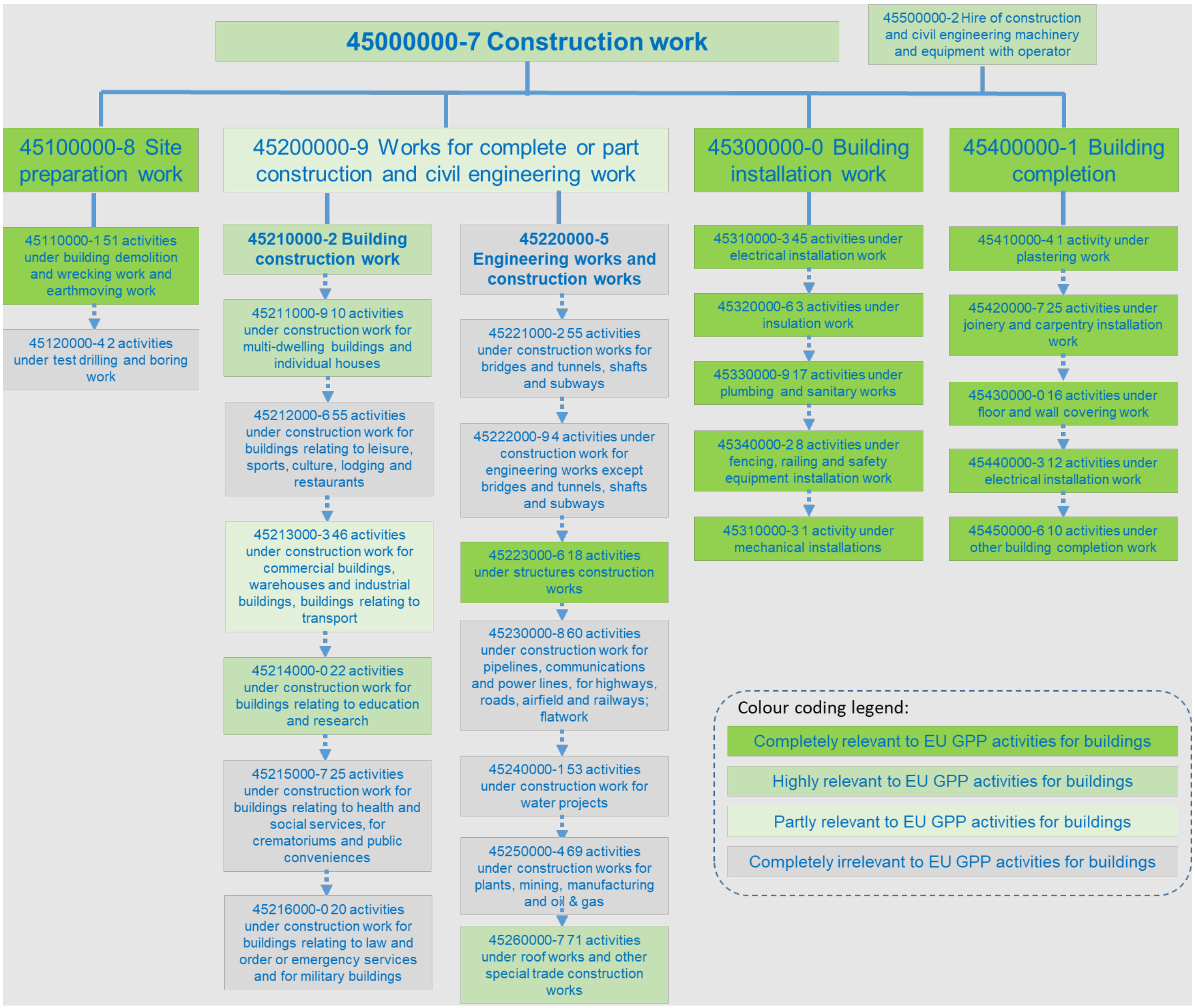
The major differences in scope are that the new criteria will also be designed to consider residential and educational buildings and will also consider criteria that could apply to the surrounding plot area of the building. The main reasons for including the building plot area is that it may be crucial in ensuring that on-site or nearby renewable energy systems are included within the scope.

Consideration of relevant Common Procurement Vocabulary (CPV) codes

In order to provide a harmonised system for public procurement, to help identify related tenders and classify public expenditure, Regulation (EC) No 213/2008[18] sets out a hierarchy of Common Procurement Vocabulary codes. A bewildering array of entries are identified when searching for terms like "buildings" or "construction" and these are compiled in Annex I for reference. When viewed in a more hierarchical form, as shown in the figure below, they become easier to understand.

18 Commission Regulation (EC) No 213/2008, amending Regulation (EC) No 2195/2002 of the European Parliament and of the Council on the Common Procurement Vocabulary (CPV) and Directives 2004/17/EC and 2004/18/EC of the European Parliament and of the Council on public procurement procedures, as regards the revision of the CPV. Available at: https://eur-lex.europa.eu/eli/reg/2008/213/oj

Figure 6. Overview of Common Procurement Vocabulary (CPV) codes for works activities in the construction sector



Source: author's own elaboration.

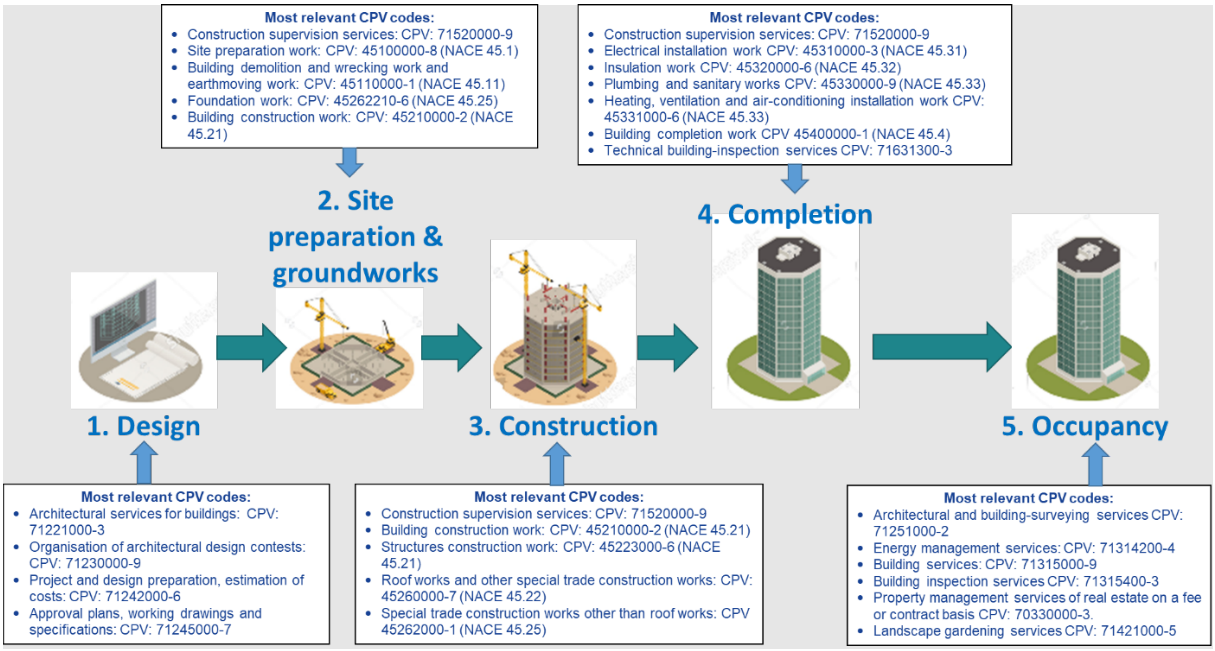
The CPV hierarchy generally follows the order in which different works would take place as time progresses in a building project, i.e. generally reading the hierarchy from left to right and ignoring most of the activities in the third column that are to do with civil engineering works and are not building-orientated.

Looking at the hierarchy above, any of the activities within the first, second, fourth and fifth columns could be relevant in the public procurement of a new building. Some entries are in grey in the second column due to the limitation of the proposed scope of public buildings.

The importance of each activity in the third, fourth and fifth columns will of course depend on the nature of the building and the site where it will be constructed. Some of the grey civil engineering activities in the third column could also become relevant if the construction project is especially large (e.g. a housing development) and/or remote from existing sewerage networks or roads and if on-site or nearby energy generation is to be included (e.g. district heating or renewable installations). However, it should be considered whether these civil engineering works are part of the same subject matter or should be subject to a separate procurement exercise, especially considering the different economic operators that would typically be involved.

In addition to works, there are also a number of services that are relevant to a building project. These services also have CPV codes listed in Regulation (EC) No 213/2008. Some of the more relevant and general services (and works) that could apply to different stages of a building project are shown below.

Figure 7. Illustration of different CPV codes (works and services) that can apply at different stages of a building's life cycle



Source: author's own elaboration.

There are many other works and services with specific CPV codes that could be considered relevant. However, in order to be concise, only some of the higher level works and services have been mentioned in the illustration above.

At the design stage, the importance of architectural services cannot be overestimated. Depending on the available budget and the novelty of the building, architectural design contests may be relevant. Once a conceptual design is agreed, it is important to carry out a more detailed design that can be approved by planning authorities and that can allow for a more accurate estimation of costs. If a building is more standardised, a lot less work will be required at this stage.

The extent of site preparation work required and the degree of supervision necessary will depend on site-specific factors. Much greater control and supervision will be needed in sites located in densely populated urban areas, where demolition may be required and the proximity of existing services or even metro lines need to be considered, compared to a rural greenfield site. Groundworks will also vary greatly depending on the underlying soil and water table. If any underground floors are planned and foundations need to go deeper, this will affect the quantity of soil to be excavated. Depending on the history of the site, there may be a risk that excavated soil is contaminated and may need to be treated as hazardous waste.

Construction activities will be influenced by the building form and structure (e.g. cross-laminated timber, steel or reinforced concrete) and shell used in the building and the extent of prefabricated elements that are used. The structure will also influence the type and specification of foundations needed.

Building completion refers to electrical installations such as wiring, alarms, antennae, aerials, lightning-protection, lifts, escalators, telecommunications equipment, cabling, electricity supply and transformer stations, lighting and other electrical equipment. It also refers to the installation of thermal and sound insulation, and to the installation of plumbing and sanitary equipment, such as central-heating systems, boilers, ventilation systems, air conditioners, water plumbing, drains, fitting of taps, sinks, toilets and showers, gas piping and related fittings.

There are EU GPP criteria on the DG Environment website[19] for the following product groups related to buildings:

- Sanitary tapware (2013) (outdated);
- Flushing toilets and urinals (2013) (outdated);
- Paints, varnishes and road markings (2018).

Although the EU GPP criteria for the products listed above are relatively old, there may be useful references to standards and methodologies. Where relevant, data and preparatory research conducted for ecodesign impact assessments for products and technical systems that are used in buildings will be considered in more detail, when assessing the improvement potential for the different topics in Task 4.

Relevant services for an occupied building that could fall within EU GPP criteria would generally refer to the regular management of the building, the operation and maintenance of its technical systems (e.g. heating, cooling, ventilation and lighting) and routine maintenance of building elements. Other services such as cleaning, security or tenant management or leasing and the maintenance of landscaped areas should be considered as subject matter for different tenders. In fact, the Commission has already published EU GPP criteria on the DG Environment website; for:

- Public space maintenance, see staff working document (2019) 404[20];
- Indoor cleaning services, see staff working document (2018) 443[21].

Since the scope for the new EU GPP criteria for buildings is expanding from just office buildings to also include residential and educational buildings, it is worth explaining how the CPV codes distinguish between construction works for different building functionalities.

Table 4. Different types of building considered in CPV codes

Building group type	Specific categories and codes
Construction work for multi-dwelling buildings and individual houses (45211000-9)	Construction work for houses (45211100-0); Sheltered housing construction work (45211200-1); Houses construction work (45211300-2).
Construction work for buildings relating to leisure, sports, culture, lodging and restaurants (45212000-6);	Construction work of leisure facilities (45212100-7); Construction work for sports facilities (45212200-8); Construction work for art and cultural buildings (45212300-9); Library construction work (45212330-8); Accommodation and restaurant buildings (45212400-0); Kitchen or restaurant conversion (45212500-1); Pavilion construction work (45212600-2).

[19] Green Public Procurement Criteria and Requirements. Available at DG Environment website https://green-business.ec.europa.eu/green-public-procurement/gpp-criteria-and-requirements_en

[20] Commission staff working document. EU green public procurement criteria for public space maintenance, Brussels, 13.11.2019 (SWD(2019) 404 final). Available at: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/3dbf0d36-3a89-4a31-a96f-e0cd06fda842/details

[21] Commission staff working document. EU green public procurement criteria for indoor cleaning services, Brussels, 11.10.2018 (SWD(2018) 443 final). Available at: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/c9b70f95-939c-464d-8107-d43cdb59d55a/details

Construction work for commercial buildings, warehouses and industrial buildings, buildings relating to transport (45213000-3)	Construction work for commercial buildings (45213100-4); Construction work for warehouses and industrial buildings (45213200-5); Buildings associated with transport (45213300-6); Installation of staff rooms (45213400-7).
Construction work for buildings relating to education and research (45214000-0)	Construction work for kindergarten buildings (45214100-1); Construction work for school buildings (45214200-2); Construction work for college buildings (45214300-3); Construction work for university buildings (45214400-4); Construction work for buildings of further education (45214500-5); Construction work for research buildings (45214600-6); Construction work for halls of residence (45214700-7); Training facilities building (45214800-8).
Construction work for buildings relating to health and social services, for crematoriums and public conveniences (45215000-7)	Construction work for buildings relating to health (45215100-8); Construction work for social services buildings (45215200-9); Construction work for social facilities other than subsidised residential accommodation (45215220-5); Construction work for crematoriums (45215300-0); Cemetery works (45215400-1); Public conveniences (45215500-2).
Construction work for buildings relating to law and order or emergency services and for military buildings (45216000-4)	Construction work for buildings relating to law and order or emergency services (45216100-5); Construction work for buildings relating to emergency services (45216120-1); Construction work for military buildings and installations (45216200-6).
Inflatable buildings construction work (45217000-1)	-

Source: author's own elaboration.

The terms in the table above should be used as far as possible when defining the scope of the EU GPP criteria for buildings.

Scope proposal and definitions

The proposal for the scope of buildings to be covered corresponds to the following:

> "The procurement of any works or services for the design, site-preparation, construction, completion or renovation of social housing, office buildings and buildings relating to educational and any multi-functional buildings where one of the aforementioned functions accounts for at least 50% of the gross internal floor area."

For the purposes of these EU GPP criteria proposals, the following definitions apply:

- "**Buildings relating to educational services**" means buildings whose primary function is the teaching of students and includes kindergartens, primary schools, secondary schools, special needs schools, vocational colleges, technical colleges and university buildings.

- "**Buildings related to social services**" means buildings whose primary function is the provision of social services and includes retirement homes, nursing homes, children's homes, day-care centres and civic centres. Moreover, social housing considered as housing that is provided at prices below normal market rates to target groups of disadvantaged people, socially less advantaged people or key workers is also included within this category.
- "**Completion**", in the context of a building project, means works or services relating to the installation of electrical infrastructure, lifts, escalators, telecommunications equipment, illumination equipment, thermal insulation, sound insulation, plumbing, sanitary works, heating, ventilation, air-conditioning, drains, gas fittings, railings, fencing, fire-prevention features, doors, windows and related components, suspended ceilings, partition walls, fitted kitchens, internal floor and wall coverings, outdoor cladding and paving as well as any other works relating to plastering, joinery and carpentry, painting, surface protection or façade.
- "**Construction**", in the context of a building project, means works or services relating to building foundations, structure, structural shell, parking lot (if within the building plot area), roof works, scaffolding, concrete work, structural steel erection work and masonry and bricklaying work.
- "**Design**", in the context of a building project, covers architectural, feasibility study, engineering, planning, specifications drafting, surveying, working drawings, approval planning and cost estimation services relating to conceptual and detailed designs for a new or renovated building.
- "**Management**", in the context of a currently occupied building, means the routine maintenance of building facilities, including sanitary fittings, security features and technical systems, as well as the operation and optimisation of energy systems, reporting on building performance to occupants about factors such as specific energy consumption, CO_2 emissions, specific water consumption or Indoor Air Quality and periodically evaluating occupant satisfaction with the building performance.
- "**Office buildings**", means buildings whose primary function is to provide space for administrative financial, professional or customer services. The office area must make up a significant majority of the whole building's total area. The building may also comprise other type of spaces, like meeting rooms, training classrooms, staff facilities, or technical rooms.
- "**Renovation**", in the context of a building project, means construction and/or demolition works to improve aspects of a building. Renovation activities can vary in terms of their depth (percentage of floor area for example affected by the renovation activity) and their primary focus (e.g. replacement/upgrading of building energy systems, façade replacement, new windows, floor and wall coverings, etc.)
- "**Residential buildings**" means buildings whose primary function is to provide private living spaces for people and includes multi-dwelling buildings, individual houses or sheltered housing. Social housing is included in this category.
- "**Site preparation**", in the context of a building project, means works or services relating to demolition, excavation, earthmoving and land reclamation.

The definitions relating to building project stages and building types have been adapted but are broadly aligned with the structure and hierarchy of Common Procurement Vocabulary (CPV) codes[22]. The definition of office buildings remains the same as in the 2016 EU GPP criteria[17].

[22] COMMISSION REGULATION (EC) No 213/2008 of 28 November 2007 amending Regulation (EC) No 2195/2002 of the European Parliament and of the Council on the Common Procurement Vocabulary (CPV) and Directives 2004/17/EC and 2004/18/EC of the

Rationale for scope proposal and definitions

Before justifying the choice of scope, the caveat that EU GPP criteria are voluntary and that public authorities can decide to apply only one or any number of them to suit their needs must be mentioned. This flexibility means that the criteria could potentially be applied to almost any type of building procurement.

However, since the scope will influence the type of criteria that are proposed and will direct the focus of the background research, it is important to decide on a particular scope at the beginning.

The general expansion of the scope is to increase the potential impact that EU GPP criteria can have on the building sector. Office buildings remain in the scope as was the case with the 2016 EU GPP criteria. By including residential buildings and buildings related to educational and social services, the scope now covers those public-owned buildings where citizens tend to spend the majority of their time.

The suggestion for libraries to be included is made because they fall somewhere between educational and social services but are neither one nor the other in the strictest sense, being considered more as a public amenity.

The definitions relating to building project stages and building types are broadly aligned with the structure and hierarchy of Common Procurement Vocabulary (CPV) codes. The definition of office buildings remains the same as in the 2016 EU GPP criteria.

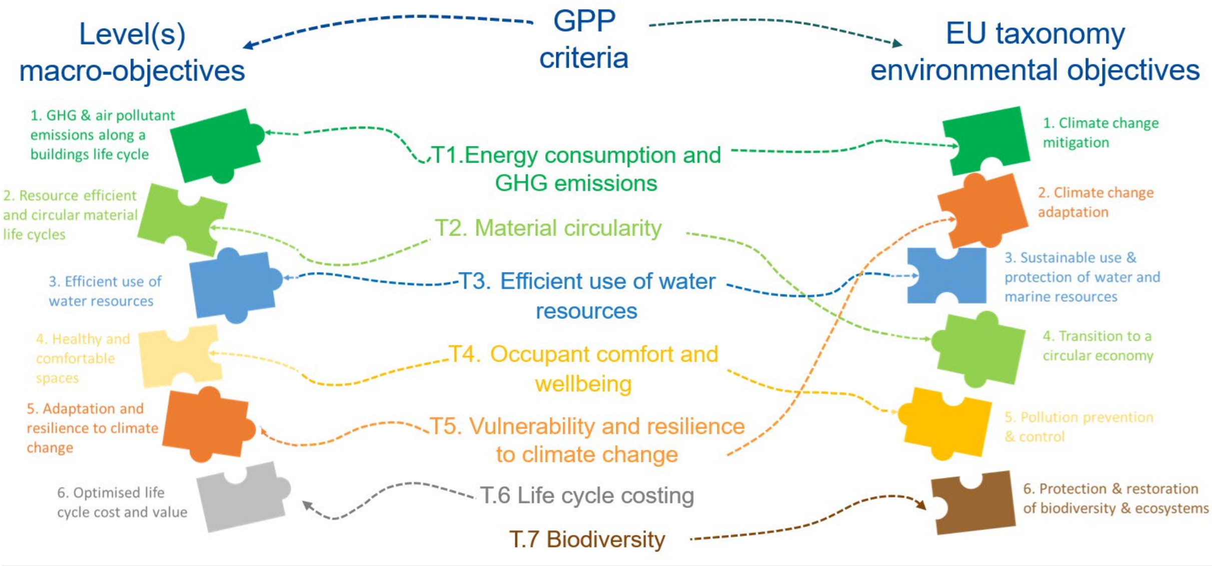
Division of the EU GPP criteria for buildings into themes

The EU GPP criteria for buildings have been organised in different themes. Each of them is related to a macro-objective to address key sustainability aspects over the building life cycle. In order to define the themes, inspiration is taken from relevant EU policy initiatives on the topic: Level(s) and the EU Taxonomy.

There is actually a close overlap between the Level(s) macro-objectives and the EU Taxonomy for environmentally sustainable economic activities, which is illustrated below.

European Parliament and of the Council on public procurement procedures, as regards the revision of the CPV. Available here: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0213

Figure 8. Commonalities between Level(s) and the EU Taxonomy



Source: author's own elaboration.

The illustration shows that five of the six macro-objectives of the Level(s) framework line up completely (macro-objectives 1, 2, 3 and 5) or partially (macro-objective 4) with the environmental objectives of the EU Taxonomy. The main difference between these two policies is that Level(s) looks at Life Cycle Cost and value while the EU Taxonomy looks at biodiversity.

Consequently, a total of seven themes are considered when drafting criteria proposals for buildings EU GPP. These themes are as follows:

1. Energy consumption and life cycle greenhouse gas emissions
2. Material efficiency and circularity
3. Efficient use of water resources
4. Occupant comfort and wellbeing
5. Vulnerability and resilience to climate hazards
6. Life Cycle Costing
7. Biodiversity

Relevant policy, legislation and technical standards by theme

With the general themes for EU GPP criteria for buildings having been defined by the Level(s) framework and the EU Taxonomy for sustainable economic activities, and the scope of buildings having been defined, it is now worth reviewing the most relevant policy, legislation and technical standards for each theme.

Theme 1: Energy consumption and life cycle greenhouse gas emissions

Energy Performance of Buildings Directive (EPBD) No EU/2024/1275[23]**:** The EPBD is the key legislative instrument for implementing and monitoring the evolution of the energy performance of the EU's building stock. Due to differences in national or regional approaches to energy performance assessment and differences in climate, culture and associated building forms and materials, the EPBD sets out an overarching methodology with various points of freedom for Member States.

These freedoms extend also to the definition of Nearly Zero Energy Buildings (NZEBs), Zero Emission Buildings (ZEBs), the scope of assessment (e.g. heating only or other energy-consuming building technical systems) and the setting of thresholds for different classes in Energy Performance Certificates.

In comparison to the previous 2010/31/EU[24], the directive now refers to Zero Emission Buildings (ZEBs), thus recognising the link between energy and carbon emissions and acknowledging that zero emission is a broader objective that combines energy performance with the use of renewable energy to supply the reduced energy demand (i.e. accounting for the quantity and carbon factor(s) of energy needed). As long as zero emission efforts are underpinned by energy efficiency first principles, the synergy between energy efficiency and reduced carbon emissions can be ensured. In Article 7, the EPBD recast sets provisions on all new buildings to be zero emission and have a life cycle Global Warming Potential (GWP) assessment by 2030 (by 2028 for new buildings owned by public bodies and with a useful floor area >1 000 m^2, respectively).

Energy Efficiency Directive (EED) No 2023/1791/EU[25]**:** As explained in the introduction, the EED aims at reducing the overall energy consumption by improving energy efficiency. Article 5 obliges the public sector to lead the way in energy efficiency, ensuring that the total final energy consumption of all public bodies combined is reduced by at least 1,9 % each year, when compared to 2021. Specifically for buildings, it requires that at least 3% of the of the total floor area of heated and/or cooled buildings that are owned by public bodies is renovated to be transformed into at least nearly zero-energy buildings or zero-emission buildings in accordance with Article 9 of Directive 2010/31/EU. Moreover, Article 7 of the EED obliges contracting authorities and contracting entities to purchase only those products, services or buildings that have high energy-efficiency performance, unless it is not technically feasible, and encourages to require that tenderers disclose information on the life cycle global warming potential, the use of low carbon materials and the circularity of materials used for a new building and for a building to be renovated, in particular for new buildings having a floor area larger than 2 000 m^2.

Product policies: The EU energy labelling (2017/1369/EU)[26] and Ecodesign for Sustainable Product Regulation (ESPR)(2024/1781/EU)[27] help improve the efficiency of products on the EU market to reduce the consumption of energy and other natural resources in line with improving overall sustainability. The energy labels provide a clear and simple indication of the energy efficiency and other key features of products at the point of purchase to guide consumers' decisions to save money

[23] Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive

[24] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Available at: https://eur-lex.europa.eu/eli/dir/2010/31/oj

[25] Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast).
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766

[26] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU. Available at: https://eur-lex.europa.eu/eli/reg/2017/1369/oj

[27] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC.
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746

on their energy bills and contribute to reducing greenhouse gas emissions across the EU. The ESPR, which entered into force on 18 July 2024, is the cornerstone of the Commission's approach to more environmentally sustainable and circular products The ESPR aims to significantly improve the circularity, energy performance and other environmental sustainability aspects of products placed on the EU market. By doing so, a significant step will be taken towards better protecting our planet, fostering more sustainable business models and strengthening the overall competitiveness and resilience of the EU economy.

Although these product policies aim to cover cross-cutting technologies in all consumer sectors, they mainly regulate equipment used in the building sector. Implementing measures under the previous Ecodesign Directive (2009/125/CE)[28] include the following equipment used in buildings: space heating, space cooling, ventilation, water heating), lighting, electronic devices, refrigerators and freezers, cooking appliances and cleaning appliances (washing machines, dryers, dishwashers, vacuums).

Commission Communications: These address the importance of improving the energy consumption of buildings to not only achieve energy savings but also to reduce carbon emissions at EU level. The Communication on the EU's 2030 climate ambition, where a 55% reduction in net CO_2 emissions compared to 1990 levels is to be aimed for by 2030, emphasises the importance of the role of energy renovation of buildings when it says:

"The building sector, currently responsible for 40% of final energy and 36% of greenhouse gas emissions in the EU, has a large cost-effective potential to reduce emissions. Today, 75% of the EU's building stock is energy inefficient[29]. Many homes are still heated with outdated systems that use polluting fossil fuels such as coal and oil. To fully tap into this potential for improvement would require the renovation rate, which is around 1% today, to double and more in the period up to 2030. In particular, deep renovations addressing building shells, smart digitalisation and the integration of renewable energy together need to increase strongly."

The urgent need for building renovation activities to meet the ambitious 2030 net carbon emission targets is well captured in the Renovation Wave Communication COM(2020)662, when it says:

"To achieve the 55% emission reduction target, by 2030 the EU should reduce buildings' greenhouse gas emissions by 60%, their final energy consumption by 14% and energy consumption for heating and cooling by 18% (compared to 2015 levels). It is therefore urgent for the EU to focus on how to make our buildings more energy-efficient, less carbon-intensive over their full life-cycle and more sustainable. Applying circularity principles to building renovation will reduce materials-related greenhouse gas emissions for buildings.

Today, only 11% of the EU existing building stock undergoes some level of renovation each year. However, very rarely, renovation works address energy performance of buildings. The weighted annual energy renovation rate is low at some 1%. Across the EU, deep renovations that reduce energy consumption by at least 60% are carried out only in 0.2% of the building stock per year and in some regions, energy renovation rates are virtually absent. At this pace, cutting carbon emissions from the building sector to net-zero would require centuries. It is time to act."

It is worth noting how the Renovation Wave Communication also highlights the importance of embodied carbon in construction materials.

A special focus on heating and cooling systems is stated in Commission Recommendation (EU) 2019/786 on building renovation, which states in recital 3:

[28] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast). Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0125

[29] The same communication states here that: "New buildings today consume only half as much as typical buildings from the 1980s. About 35% of the EU's buildings are over 50 years old.

"The 2015 Paris Agreement on climate change following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) boosts the Union's efforts to decarbonise its building stock. Given that almost 50 % of the Union's final energy consumption is for heating and cooling, of which 80 % is used in buildings, the Union's achievement of its energy and climate goals is linked to its efforts to renovate building stocks by giving priority to energy efficiency, applying the 'energy efficiency first' principle and considering the deployment of renewables."

EN standards: In terms of technical standards, there are two separate CEN Technical Committees working on energy performance methods (CEN/TC 371) and on life cycle carbon emissions from buildings (CEN/TC 350). Some of the main standards are presented below:

- CEN/TC 371: the overarching series of EN ISO 52000 standards on an all-encompassing Energy Performance of Buildings assessment.
- CEN/TC 350: the main standard of reference here is EN 15978, setting out a calculation method for a building's environmental performance over its entire life cycle. This method at building level is complimented by a related standard (EN 15804) that applies at the level of construction products.

Other EN standards that are related to the energy performance in buildings and useful for the definition of the EU GPP criteria are EN 13187 for testing the building form for thermal defects via thermal imaging and EN ISO 9972 setting out the methods for air permeability tests (CEN Technical Committee CEN/TC 89 - Thermal performance of buildings and building components).

Level(s): Level(s) has two relevant indicators related to this Theme. The first one is indicator 1.1 on use stage energy consumption, where results should be reported in units of kWh/m^2/yr of primary energy in accordance with applicable national or regional methods. This result may be split into non-renewable and renewable and into "self-used" or "balance", where the latter allows for subtracting any exported energy produced on site.

The second indicator is 1.2 on life cycle carbon emissions, where results are to be reported in terms of fossil Global Warming Potential (GWP), biogenic GWP and land use and land use change GWP across the modules A to D of a building life cycle as defined in EN 15978. The details of the Level(s) method, which is explicitly referred to in the EPBD recast for life cycle GWP calculations, is in line with EN 15978 but defines a minimum scope for building elements to be covered in embodied carbon calculations.

EU Taxonomy: As indicated in **Figure 2**, Theme 1 is very well aligned with macro-objective 1 of Level(s) and the climate change mitigation environmental objective of the EU Taxonomy.

The EU Taxonomy, as part of defining a significant contribution to climate change mitigation, requires that the construction of new buildings has a calculated primary energy demand that is 10% lower than the threshold set for NZEB buildings in the same country and that energy performance is reported on an EPC. Furthermore, for any new buildings >5 000 m^2, a life cycle GWP assessment shall be carried out in line with Level(s) indicator 1.2. For the acquisition of buildings, they shall have at least an Energy Performance Certificate class A or be within the top 15% of the national or regional building stock expressed as operational Primary Energy Demand if built before 31 December 2020; otherwise, their primary energy demand shall be 10% lower than the threshold set for NZEB buildings, despite not being a new construction. For building renovation, the renovation activity must meet the relevant national definition of "major renovation" defined in line with the EPBD or deliver a reduction of primary energy demand of at least 30%.

Moreover, it also requires buildings' components and systems installed, maintained or repaired to comply with minimum requirements in the applicable national measures implementing Directive 2010/31/EU and, where applicable, be rated in the highest two populated classes of energy efficiency in accordance with Regulation (EU) 2017/1369 and delegated acts adopted under that Regulation.

Theme 2: Material efficiency and circularity

Material efficiency is a broad concept whose main facets are:

- using less materials in the first place to meet a given need or function;
- construction or demolition processes that produce less waste and/or site waste management procedures that segregate CDW to maximise its potential for recycling and recovery;
- building elements that last longer, either because they are more durable or easy to adapt and repair;
- building designs that facilitate the disassembly and reuse of building elements at the end of life.

Greater material efficiency can not only deliver significant reductions in total EU waste generation, but also make a significant contribution to reducing greenhouse gas emissions, thus working in tandem with Theme 1.

Legislation: The Waste Framework Directive, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, under revision to be aligned to the European Green Deal and the Circular Economy Action Plan, lays down "Measures to protect the environment and human health by preventing or reducing the generation of waste, the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use, which are crucial for the transition to a circular economy and for guaranteeing the Union's long-term competitiveness."

The Waste Framework Directive 24 (WFD) is the single most important piece of EU legislation in relation to CDW. The WFD defines a waste hierarchy of: prevention > preparing for reuse > recycling > other recovery > disposal and had set a target of 70% of CDW being prepared for reuse, recycled or materially recovered (including backfilling) by 2020 for each Member State. New targets for CDW will be considered by 31 December 2024 and these new targets may also be applied to specific fractions of CDW.

The foundation of EU waste management is the five-step "waste hierarchy", that establishes the following order of preference for managing and disposing of waste: prevention; preparing for reuse; recycling; other recovery and disposal.

The Proposal for a Regulation of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011, enhances the revision of the Construction Product Regulation, among other reasons, to give preference to recyclable materials and materials gained from recycling; to respect the minimum recycled content obligations and other limit values regarding aspects of environmental sustainability and to design products in such a way that reuse, remanufacturing and recycling are facilitated.

The EU Construction and Demolition Waste Protocol and Guidelines are based on the proper management of Construction and Demolition Waste and recycled materials – including the correct handling of hazardous waste which can provide major benefits for the EU construction and recycling industry, as it boosts demand for C&D recycled materials.

Commission Communications: The Circular Economy Action Plan, *Communication from the Commission to The European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions a new Circular Economy Action Plan for a cleaner and more competitive Europe (COM/2020/98 final)* states:

"The construction sector is responsible for over 35% of the EU's total waste generation (Eurostat, 2016). Greenhouse gas emissions from material extraction, manufacturing of construction products, construction and renovation of buildings are estimated at 5-12% of total national GHG emissions25. Greater material efficiency could save 80% of those emissions."

The Renovation Wave for Europe, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions a Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM/2020/662 final, aims at "Making the construction ecosystem fit to deliver sustainable renovation, based on circular solutions, use and reuse of sustainable materials, and the integration of nature-based solutions. The Commission proposes to promote the development of standardised sustainable industrial solutions and the reuse of waste material. It will develop a 2050 roadmap for reducing whole life-cycle carbon emissions in buildings, including through the use of biobased products, and review material recovery targets."

EN and ISO standards:

The International Cost Management Standard is highly relevant in terms of material footprint when estimating the bill of quantities, because this has a direct relationship to the cost of a building project. This facet of material efficiency also has a clear link to Life Cycle Costing in Theme 6, and in particular when lifespans of building elements and components are considered. Likewise, when embodied carbon is associated with material quantities, a link to Theme 1 is established.

EN 15643-3 considers adaptability as one of the aspects of the social performance framework for a building. The four main features of adaptability described therein are: (i) ability to accommodate individual user requirements (e.g. need for private working spaces and group working spaces); (ii) ability to accommodate changes in user requirements (e.g. need bathroom on ground floor of a house, need an extra bedroom in a flat, merging classrooms for large events); (iii) ability to accommodate technical changes (e.g. change of heating system) and (iv) the ability to accommodate changes of use (e.g. office to residential).

EN 16309 is linked to EN 15643-3 and provides more details about how to assess and communicate the adaptability of a building against different scenarios within the EN 15978 life cycle framework. It can be argued that other social performance aspects that are mentioned in EN 16309 such as Indoor Air Quality and thermal comfort are being part of the concept of "adaptability", but these are treated separately in the EU GPP criteria structure, under Theme 4. A similar case applies to the social performance of buildings in terms of resistance to climate hazards, which is covered separately under Theme 5.

The ISO 20887 standard addresses design for adaptability concepts using the following terms: (i) versatility (i.e. how to accommodate different use needs simultaneously); (ii) convertibility (i.e. how to accommodate intermittent changes of use) and (iii) expandability (i.e. how to increase available space or functionalities of the building).

The adequate design of buildings for deconstruction can make a major contribution to the circular economy in the medium- to long-term future, when buildings are under renovation or reach the end of their lives. Such design principles are in line with the Buildings As Material Banks (BAMB) concept. The BAMB research group have promoted the idea of material passports, which manufacturers would provide to their customers and which inform about how the product can be disassembled and what options are available for its reuse, recycling or recovery at the end of life. While material passports are of clear value in improving the circularity of material flows in the building sector, the ultimate goal is to put this all together to drive reversible building design. 20887 refers to some key underlying disassembly principles, namely: ease of access to connections of components and services; independence of connections; reversibility of connections; avoidance of unnecessary treatments and finishes; simplicity of design; standardisation and safety of disassembly.

Level(s): The different facets of material efficiency are covered in the Level(s) framework under the following indicators:

- Indicator 2.1: bill of quantities, materials and lifespans.
- Indicator 2.2: Construction and Demolition Waste (CDW) and materials.

- Indicator 2.3: design for adaptability and renovation.
- Indicator 2.4: design for deconstruction.

The Level(s) methodology already defines a scoring matrix for quantifying the adaptability of office buildings (in the indicator 2.3 user manual) and a scoring method for quantifying the design for deconstruction of buildings.

EU Taxonomy also considers targets for CDW from new construction, demolition and renovation activities for demonstrating a significant contribution to a circular economy.

Theme 3: Efficient use of water resources

Legislation: The overarching EU policy that covers the efficient use of water resources is the EU Water Framework Directive[30]. The principle aim of the Directive is to protect and enhance the status of aquatic ecosystems. Such an aim goes hand in hand with the efficient use of water resources, since excessive water abstraction will place more pressure on aquatic ecosystems and any abstracted water returning to the same natural watercourse will be coming via wastewater plant discharges or agricultural runoff, thus bringing pollutants and having an adverse effect on water quality in that natural watercourse.

Commission Communications: COM(2008)414 on addressing the challenge of water scarcity and droughts in the European Union proposed the creation of a European Drought Observatory, which was later set up and which provides a wealth of drought data that could potentially be used by relevant authorities to take actions in real time that could reduce water demand (e.g. water pricing control for customers or setting limits on abstraction limits).

Another initiative proposed by the Communication was to explore the possibility of expanding existing EU labelling schemes for water-consuming devices and fittings. Today, there are two main voluntary labelling schemes operating at the European level: the European Water Label and related the Unified Water Label. These labelling schemes offer searchable databases of products for consumers to compare and select tap, shower, and toilet-related products with a known water efficiency.

EN standards: In terms of technical standards, there are two separate CEN Technical Committees working on sanitary appliances (CEN/TC 163), on water supply (CEN/TC 164) and, as far as rainwater and grey water are concerned, part of CEN/TC 165 (wastewater engineering). Some of the main standards are presented below.

- CEN/TC 163: Performance requirements and test methods for different types of WC pans with integral traps (EN 997), wall-hung urinals (EN 13407), WC and urinal flushing cisterns (EN 14055) and wash basins (EN 14688).
- CEN/TC 164: Technical specifications for sanitary tapware of various types and fittings (EN 200, EN 246, EN 816, EN 817, EN 1111, EN 1112, EN 1113, EN 1286, EN 1287).
- CEN/TC 165: Onsite non-potable water systems for rainwater (EN 16941-1) and for treated greywater (EN 16941-2).

Because of the potential benefits of linking rainwater harvesting and grey water reuse to irrigation, it is proposed to explore further standards relating to irrigation and the different types of systems available. Irrigation will generally be more important for buildings with large plot areas (e.g. schools) but could also apply even to buildings in dense urban environments if green roofs and/or green walls are used.

[30] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy"

Level(s): Indicator 3.1 in the Level(s) framework is specifically about water consumption and provides a bespoke calculator that allows users to adjust usage factors and specific water consumption rates of taps, showers, bathtubs, toilets and urinals as well as estimating potential inputs from rainwater harvesting or grey water recycling systems. Results are calculated in units of m^3/occupant/year and can be split into potable water (mains) and non-potable fractions.

EU Taxonomy: In addition to technical screening criteria for Do No Significant Harm for "Sustainable use and protection of water and marine resources", the technical screening criteria for Do No Significant Harm for climate change mitigation set upper limits for the specific water consumption of different sanitary fittings.

Theme 4: Occupant comfort and wellbeing

Occupant comfort and wellbeing is a complex and often subjective quality that architects, designers and engineers have made a great deal of effort to understand and optimise. Many of the different facets of occupant comfort and wellbeing are interrelated as well and trade-offs exist. For example, Indoor Air Quality, in terms of the concentration of pollutants present in the air, is influenced both by the sources of those pollutants (indoors and outdoors) and indoor-sourced pollutants which can be reduced by ventilating. However, ventilating affects the indoor temperature and thus thermal comfort of occupants and can generate more noise, either by allowing outdoor noise in via open windows or by the running of ventilation equipment. Hence, a balance needs to be struck both between different facets of occupant comfort and between occupant comfort and energy consumption (link to Theme 1).

Legislation: Many of the building technical systems used in buildings to maintain occupant comfort are covered by the Ecodesign Directive and the Energy Labelling Framework Regulation. Some of the most relevant product groups and associated energy labelling Regulations include:

- Water heaters: Commission Delegated Regulation (EU) No 812/2013[31].
- Air conditioners: Commission Delegated Regulation (EU) No 626/2011[32].
- Local space heating appliances: Commission Delegated Regulation (EU) No 2015/1186[33].
- Light sources: Commission Delegated Regulation (EU) No 2019/2015[34].
- Residential ventilation units: Commission Delegated Regulation (EU) No 1254/2014[35].

The quality of an environment inside a building is to some extent influenced by the quality of the environment immediately outside the building. In this sense, it is worth mentioning the Environmental

[31] Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32013R0812

[32] Commission Delegated Regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32011R0626

[33] Commission Delegated Regulation (EU) 2015/1186 of 24 April 2015 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of local space heaters. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.193.01.0020.01.ENG

[34] Commission Delegated Regulation (EU) 2019/2015 of 11 March 2019 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of light sources and repealing Commission Delegated Regulation (EU) No 874/2012. Available at: https://eur-lex.europa.eu/eli/reg_del/2019/2015/oj

[35] Commission Delegated Regulation (EU) No 1254/2014 of 11 July 2014 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of residential ventilation units. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.337.01.0027.01.ENG

Noise Directive (2002/49/EC)[36] which provides a methodological approach for mapping noise in urban areas and the Air Quality Directive (2008/50/EC)[37] for the monitoring and control of fine Particulate Matter, ozone, sulphur oxides, nitrogen oxides carbon monoxide and benzene in ambient air.

EN standards: The EN 15643 standard considers the concept of "health and comfort" as a key part of the social performance framework for buildings. Within this concept, EN 15643-3 refers to:

- acoustics,
- Indoor Air Quality,
- visual comfort,
- water quality,
- spatial characteristics, and
- thermal characteristics.

The current (2014) version of EN 16309 provides information on assessing all of these aforementioned characteristics except for water quality. It splits these aspects into: (i) those that are determined by the building-fabric and (ii) those that are determined by user and control system interactions.

The main Technical Committees involved in EN standards regarding occupant comfort are as follows:

- CEN/TC 122 for ergonomics of the physical environment, specifically standards that relate to the thermal environment, for example EN ISO 11399 on basic principles, EN ISO 10551 for subjective judgements, EN ISO 7243 and 7933 for heat stress, and EN ISO 15265 on stress prevention EN ISO 7730 on the analytical determination of thermal comfort, EN ISO 7726 on instrumentation to measure physical quantities.
- CEN/TC 156 for ventilation for buildings, which includes standards relating to naturally and mechanically powered residential ventilation, ductwork, air terminal devices, air handling units, fans, louvres, cowls and roof outlets for ventilation and cooling systems. Of particular relevance are the EN 16798 series of standards and the restructuring of other EN standards into this series: EN 15251 → EN 16798-1; EN 13779 → EN 16798-3; EN 15241 → EN 16798-5-1+EN 16798-5-2; EN 15242 → EN 16798-7; EN 15243 → EN 16798-9 and EN 15239+EN15240 → EN 16798-17.
- CEN/TC 169 for lighting applications, especially EN 12464-1 for lighting of workplaces indoors, EN 15193-1 on energy requirements for lighting and EN 17037 on daylight in buildings.
- CEN/TC 195 for air filters for general air cleaning, with specifications for particulate removal (especially the EN 16890 series of standards).
- CEN/TC 228 for heating systems in buildings, for example the EN 12381 series of standards for calculating design heat load, EN 15316 series of standards on methods for calculating system energy requirements and system efficiencies and the EN 15378 series of standards on heating systems and Domestic Hot Water systems.
- CEN/TC 264 for air quality, especially the ISO 16000 series of standards on emission test chamber methods.

[36] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0050

[37] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049

- CEN/TC 351 for construction products – assessment of release of dangerous substances, and especially EN 16516.

Many of these standards fit into the modular framework for the Energy Performance of Buildings assessment (see Annex II), which stems from the overarching EN ISO 52000 series of standards.

Level(s): Given that occupant comfort is a complex issue, Level(s) presents four indicators, the latter two of which are not yet developed at all three levels that Level(s) sets out for the majority of its indicators.

- Indicator 4.1: Indoor Air Quality.
- Indicator 4.2: Time outside of thermal comfort range.
- Indicator 4.3: Lighting and visual comfort.
- Indicator 4.4: Acoustics and protection against noise.

EU Taxonomy: The Taxonomy is focused on environmental objectives whereas the concept of occupant health and comfort is more social. Nevertheless, there is a partial overlap with Level(s) indicator 4.1 on Indoor Air Quality, where the taxonomy refers to the specification of construction products and materials that have low formaldehyde emissions. The Level(s) indicator on Indoor Air Quality looks to not only limit formaldehyde emissions from construction materials, but other volatile organic compounds (VOCs) as well.

Theme 5: Vulnerability and resilience to climate change

Climate forms a key consideration in the design, construction and operation of buildings. Climate change is already causing observable effects on the environment and impacting the buildings in which we live and work. Some of these observable effects include more extreme temperatures, higher wind speeds and heavier precipitation, all of which negatively impact buildings and their users.

The EU policy framework has started to require and support more action for adapting buildings to climate change. These actions are largely still taking shape, and some are voluntary. However, climate adaptation is starting to step out of the shadow of climate mitigation. The assessment of climate risks for buildings will need to be expanded and adaptation solutions will need to be identified. ed to be extended and the decision to implement certain adaptation solutions will need to be informed.

Climate change adaptation offers co-benefits to the following:

- The decarbonisation of the building sector is addressed in most EU policy instruments and takes priority over climate adaptation in the public debate. This is because the requirements for heat and cold adaptation solutions overlap with energy efficiency measures, such as insulation and passive heating and cooling.
- The affordability of buildings represents an essential human need. Well-designed climate adaptation supports the long-term affordability of housing by reducing energy bills and repair costs in the future.
- Adaptation further contributes to life-cycle thinking in the building sector by increasing the lifetime of buildings and their reusability in response to climate hazards. Several instruments such as the CPR and Level(s) actively combine adaptation and life-cycle thinking.

At the same time, adaptation measures present some potential trade-offs with the same principles:

- Higher material use for resistance to storm, subsidence or flooding could potentially increase the embodied carbon emissions of a building. This leads to higher GHG emissions unless changes are made to the production of these materials.

- Due to special requirements, higher material needs and more complex planning, the initial costs for risk assessment, design and construction are also higher and can reduce the affordability of new buildings.

All stakeholders have to reflect on current practices to enable a stronger inclusion of considerations on climate change adaptation in the building sector.

It is important to provide increased resiliency of long-life structures to climate change consequences, with cost-effective benefits to avoid the need of later retrofitting of existing structures. The design life should consider a long-term view, beyond the original life cycle of the building and consider durability, longevity and adaptation to climate change. Generally, by applying durability, disassembly, adaptability and circularity principles, the properties of structural elements can be enhanced to enable their reuse in future life cycles.

However, another essential consideration in adaptation to climate change is not to over-design and over-specify materials to account for any possible increase in climate hazards. Instead, the right balance between structural resilience and embodied carbon emissions of structural materials should be considered. Where possible, optimisation of the design to avoid climate change impacts that do not contribute to additional structure emissions should be pursued, weighing up reduced emissions and increased longevity.

Legislation: One of the best-known and concerning climate hazards is flooding. The EU Floods Directive (2007/60/EC) set requirements for Member States to conduct a preliminary flood risk assessment of their river basins and coastal areas by 2011 and, where real risks of flood damage exist, they had to develop flood hazard maps and flood risk maps by 2013. These maps were to identify areas with a medium likelihood of flooding (at least a 1 in 100 year event) and extreme events or low likelihood events, in which expected water depths should be indicated. In the areas identified as being at risk the number of inhabitants potentially at risk, the economic activity and the environmental damage potential was to be indicated. By 2015, flood risk management plans should have been developed for areas of identified flood risk and measures to take to reduce flood risk. However, the general risk management approach does not focus at all on adaptation measures that could be applied to buildings to reduce the extent of damage caused to existing buildings in a flood event, but instead looks at broader interventions at the urban or catchment level.

The Construction Product Regulation (CPR that has been adopted by Parliament in plenary 10 April 2024. includes in the Annex I requirement that the likely impacts of climate change on the lifespan should be taken into account in standardisation requests and harmonised technical specifications covering materials (referred to as construction products) for integration into buildings (called construction works).

This means that anticipating climate risks would be legally required in all standards and technical specifications for construction products under the revised CPR, when it enters into force. This would point to the high relevance of product standards for building materials, which have so far been missing.

Commission Communications: The EU strategy on adaptation to climate change set out in Staff Working Document (2018) 461 made very limited reference to buildings, instead focusing climate-proofing actions mainly on agriculture, aquaculture and infrastructure.

In a more recent Commission Communication (COM(2021)82) on the new EU strategy on adaptation to climate change, a more specific reference is made to buildings in the following text:

"We need to do more to prepare Europe's building stock to withstand the impacts of climate change. Extreme weather and long-lasting climatic changes can damage buildings and their mitigation potential e.g. solar panels or thermal insulation after hailstorms. However, buildings can also contribute to large-scale adaptation, for example through local water retention that reduces the urban heat island effect with green roofs and walls. The Renovation Wave and the Circular Economy Action Plan identify climate resilience as a key principle. The Commission will explore options to better predict climate-induced stress on buildings and to integrate climate resilience considerations into the construction and renovation of buildings through Green Public Procurement criteria for public buildings, the Digital Building Logbook, and as part of the process to revise the Energy Performance of Buildings Directive and the Construction Products Regulation."

Of particular relevance in the above text is the intention to explore using EU GPP criteria as a tool for specifying how new buildings can be designed, or existing buildings renovated, in such a way as to reduce risks associated with climate hazards.

EN standards: The EN ISO 14090:2019 'Adaptation to climate change — Principles, requirements and guidelines' specifies the integration of adaptation within or across organisations, understanding impacts and uncertainties and how these can be used to inform decisions.

The additional EN ISO 14091:2021 'Adaptation to climate change - Guidelines on vulnerability, impacts and risk assessment' further addresses vulnerability, impacts and risk assessment for organisations in the context of climate change.

Between 2014 and 2022, CEN/CENELEC revised certain building standards to take into account future climate, steered by their Adaptation to Climate Change Coordination Group, so the development of more detailed standards for infrastructure objects and the update of existing ones will take place in the coming years.

The EU is also working on creating an EU model for Digital building logbooks for new and existing buildings that can help harmonise information on individual buildings, including the steps undertaken to adapt to climate risks.

Level(s): The Level(s) framework sets out three separate indicators relating to vulnerability and resilience to climate hazards, under macro-objective 5:

- 5.1: Protection of occupier health and thermal comfort.
- 5.2: Increased risk of extreme weather events.
- 5.3: Sustainable drainage.

With indicator 5.1, the focus is on the future thermal comfort of the occupants and the methodology and relevant EN standards are effectively the same as for assessing thermal comfort today (e.g. EN 16798). The main difference is that a projected future climate data file is used for dynamic energy simulation instead of a present-time climate data file based on historical data.

Indicators 5.2 and 5.3 are still to be fully developed and only offer guidance for conceptual design discussions in the latest versions (January 2022) of the Level(s) user manuals. Developments in the new versions of Eurocode standards for building structures will most likely have an influence on indicator 5.2 in the future.

EU Taxonomy: With climate change adaptation being one of the main environmental objectives of the Taxonomy, it is worth explaining further here the types of climate hazards that are identified in the Taxonomy.

Table 5. Climate hazards in the EU Taxonomy

	Temperature-related	**Wind-related**	**Water-related**	**Solid mass-related**
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion

	Temperature-related	Wind-related	Water-related	Solid mass-related
	Heat stress		Precipitation or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permanent thawing		Saline intrusion	Solifluction
			Sea level rise	
			Water stress	
Acute	Heatwave	Cyclone, hurricane, typhoon	Drought	Avalanche
	Cold wave / frost	Storm (including blizzards, dust and sandstorms)	Heavy precipitation (rain, hail, snow/ice)	Landslide
	Wildfire	Tornado	Flood (coastal, fluvial, pluvial, ground water)	Subsidence
			Glacial lake outburst	

Source: author's own elaboration.

Part of the requirements for the construction of new buildings or renovation of new buildings making a substantial contribution to climate change adaptation is to screen the climate hazards listed above for the projected lifetime of the building, to conduct a climate risk and vulnerability assessment for identified physical climate risks, to assess possible "adaptation solutions" to reduce the physical climate risk and finally to implement adaptation solutions. As a rule, such solutions should not transfer the climate risk elsewhere, should favour nature-based solutions as much as possible and should be monitored and measured against predefined indicators.

Theme 6: Life Cycle Costing

EU initiatives: Life Cycle Costing (LCC) is being promoted by the Commission especially in the context of Green Public Procurement, in line with the provisions made under the 2014 public procurement Directive 2014/24/EU for awarding contracts on the basis of the Most Economically Advantageous Tender (MEAT).

Life Cycle Costing makes good sense regardless of a public authority's environmental objectives. By applying LCC, public purchasers take into account the costs of resource use, maintenance and disposal which are not reflected in the purchase price. Often this will lead to 'win-win' situations whereby a greener product, work or service is also cheaper overall. The main potential for savings over the life cycle of a good, work or service are:

- savings on use of energy and water;
- savings on maintenance and replacement costs;
- savings on disposal costs (or revenues for reusable or recyclable parts).

Especially for public procurement, the Commission has developed LCC tools for the following product groups: (i) vending machines; (ii) imaging equipment; (iii) computers and monitors; (iv) indoor lighting and (v) outdoor lighting.

However, buildings are a much more complicated subject matter for procurement and the market value of a building is also highly influenced by site-specific factors and subjective and architectural factors that relate to the quality of living, working and amenity spaces provided in and around the building.

EU Legislation: The most relevant references to Life Cycle Costing are Article 68 of Directive 2014/24/EU and Article 83 of Directive 2014/25/EU, which both basically say that Life Cycle Costs must cover the costs of acquisition, of use, of maintenance and of end of life. External costs such as greenhouse gas emissions can also be counted if a monetary value can be determined, is objectively verifiable, non-discriminatory, is accessible to all interested parties and can be provided with reasonable effort by normally diligent economic operators.

EN standards: EN 15643-4 concerns the framework rules and methods for cash flow calculations over a building's life cycle, as part of the broader sustainability performance assessment framework of construction works that the EN 15643 standards cover. Many of the terms and principles used are common to the ISO 15686 series of standards. EN 16627 details the calculation method (processes, tasks and actions) and boundaries at the level of a building project and within the EN 15798 modules for a building life cycle.

The fact that renewable energy systems and energy storage systems are also being installed on and around buildings to a greater extent will also have a significant influence on Life Cycle Costing calculations and there is a separate EN standard (EN 15459-1) dedicated to the economic evaluation of energy systems used in buildings, which also falls within standardisation work related to the Energy Performance of Buildings Directive.

Because a Life Cycle Costing exercise is very complex for buildings, due to the long lifetime and large number of building elements, components, materials and technical systems of which it is composed, it is crucial for any contracting authority to clearly specify any functional requirements and use scenarios for the building, which all tenderers or designers must adhere to. Since building structure lifetime is a clear limit to the likely lifetime of a building, the Eurocodes (EN 1990 series of standards) may be used to determine upper limits for the required service life of a building.

Outside the EN standard framework, it is worth mentioning here the 3rd edition of the International Cost Management Standard (ICMS) that was published in November 2021. The standard sets out a clear hierarchy of costs, which are broadly split into: acquisition costs, operational costs and end-of-life costs and external (carbon) costs. Although the standard is designed for use beyond the EU, it also includes a mapping of the carbon costs from different parts of the ICMS3 hierarchy onto the life cycle stages of the EN 15978 life cycle framework.

Level(s): The Level(s) framework aims to promote life cycle thinking. It guides users from an initial focus on individual aspects of building performance towards a more holistic perspective, with the aim of wider European use of Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) methods. Level(s) indicator 6.1 addresses LCC. The indicator measures all building element costs incurred at each life cycle stage of a project for the reference study period and, if defined by the client, the intended service life. The indicator shall be calculated for the elemental costs of a building.

Theme 7: Biodiversity

EU initiatives: The EU Biodiversity Strategy for 2030, as set out in Communication COM(2020)380[38], aims, amongst other things, to increase "greening" of urban and peri-urban areas. European cities with populations greater than 20 000 inhabitants are called to develop ambitious "Urban Greening Plans". While there is pressure to develop urban spaces for their inherent real estate value, there are

[38] Communication from the Commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity strategy for 2030 Bringing nature back into our lives. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380

options to improve greening of existing developments, for example by installing green roofs and green walls and making use of hedges instead of walls or fencing to delimit urban spaces.

Legislation on artificial light at night: In Europe, there are not many regulations specifically targeting the protection of nocturnal species from the negative effects of Artificial Light at Night (ALAN).

At European Level, the revision of the EU Pollinators Initiative, the first-ever EU action framework to tackle the decline of wild pollinators adopted in June 2018, is coming up. Meanwhile, very few EU Member States have adopted legislation to deal with light pollution on ecological networks. Most notable is France where new laws deal with upward light emission, glare, light trespass and restrictions on the emission of blue light. Also, there is the German "insect protection" law recently implemented in the Federal Nature Conservation Act.

Standards on green infrastructure: The authors are not aware of any EN or ISO standards for the construction of green roofs or green walls. However, standards have been in place in Germany for decades via the German Landscape Research, Development and Construction Society (FLL)[39] and more recently a UK Green Roof Code of Practice[40]. Some countries have adopted the FLL guidelines verbatim and supplemented them with their own regulations (e.g. Switzerland[41]). Additionally, the following EU countries have specific standards for green walls and green roofs: Austria[42], Czech Republic[43], France[44], Italy[45], Slovakia[46] and Sweden[47,48]. There are cases in which the Regulations may differ locally, as is the case for Austria.

Interestingly, the European Federation of Green Roofs and Walls (EFB) and the Innovation Lab Grünstattgrau of Österreichischer Verband für Bauwerksbegrünung set up a mutual market research initiative to generate a comprehensive market report for the greening industry in the EU[49].

Responsible Sourcing Certification Schemes: A number of related but distinct terms are used in the efforts to advance sustainability objectives in supply chains, including: responsible sourcing, supply chain due diligence, traceability and Chain of Custody (CoC). When it comes to construction materials, besides the Forestry responsible sourcing certification schemes such as FSC[50], PEFC[51] and SFI[52], the following schemes exist and are recognised by green building rating systems like BREEAM[53]:

- CARES is an independent, not-for-profit certification and UK Conformity Assessment approved body claiming 100% traceable steels, chain of custody from mill to site. They developed their own Responsible Sourcing scheme: CARES Sustainable Constructional Steel Scheme[54].

[39] Green Roof Guidelines 2018. Available at: https://shop.fll.de/de/green-roof-guidelines-2018-download.html
[40] British code of practice and Guidelines. Available at: https://www.greenrooforganisation.org/downloads/
[41] Green roofs standards in Switzerland. Available at: http://www.webnorm.ch/normenwerk/architekt/118-312_2013_d/D/Product
[42] Green roofs and green walls standards in Austria. Available at: ÖNORM L1131, ÖNORM L1133, ÖNORM L1136
[43] Green roofs and green walls standards in Czech Republic. Available at: https://www.zelenestrechy.info/standardy-ke-stazeni
[44] Green roofs and green walls standards in France. Available at: http://www.adivet.net/component/content/article/21-realisation-toiture/96-regles-professionnelles.html
[45] UNI standard "Instructions for the design, execution, control and maintenance of green roofs" in Italy. Available at: UNI standard "Instructions for the design, execution, control and maintenance of green roofs"
[46] Slovakian Standards for the design, implementation and maintenance of green roofs. Available at: https://www.zelenestrechy.org/wp-content/uploads/2022/08/Vegetacne-suvrstvie-zelenych-striech_Standardy_-2022_SK-1-vydanie_FINAL.pdf
[47] Swedish handbook on green roofs and green walls. Available at: https://gronatakhandboken.se/
[48] Swedish guidelines on green walls and green roofs. Available at: https://green-roof.org/resources/
[49] Green Market Report. Available at: https://greenmarketreport.eu/en/green-market-report/
[50] Forest Stewardship Council. Available at: https://fsc.org/es
[51] PEFC Chain of Custody certification. Available at: https://www.pefc.org/standards-implementation
[52] Sustainable Forest Initiative. Available at: https://forests.org/es/
[53] Guidance Note 18: BREEAM Recognised Responsible Sourcing Certification Schemes and BREEAM Scheme Applicability. Available at: https://kb.breeam.com/knowledgebase/gn18-breeam-recognised-responsible-sourcing-certification-schemes-and-breeam-scheme-applicability-2/
[54]CARES certification scheme. Available at: https://www.carescertification.com/content/5abe33b0-e465-494b-be20-080daeeebb4a/CARES Sustainability Report 2021.pdf

- The Aluminium Stewardship Initiative (ASI) is a non-profit, multi-stakeholder organisation which exists to administer an independent third-party certification program for the aluminium value chain. The ASI certification program[55] provides assurance against two voluntary standards: the ASI Performance Standard[56] and the ASI Chain of Custody Standard[57].
- Concrete Sustainability Council (CSC) is the global certification system for responsibly sourced ready-mixed and precast concrete[58].
- The Natural Stone Council Chain of Custody Standard[59] based largely on the FSC Standard for Chain of Custody Certification (FSC-STD-40-004 V2-1 EN)[60].

---

[55] Aluminium Stewardship Initiative (ASI) certification program – Chain of Custody Standard (2016). Available at: https://aluminium-stewardship.org/wp-content/uploads/2015/05/ASI-CoC-Webinars-Nov2016.pdf

[56] ASI CoC Standard. Available at: https://aluminium-stewardship.org/

[57] ASI Chain of Custody Standard Guidance. Available at: https://aluminium-stewardship.org/asi-standards/chain-of-custody-standard

[58] Concrete Sustainability Council (CSC). Available at: https://csc.eco/

[59] Natural Stone Council Chain of Custody Standard. Available at: https://naturalstonecouncil.org/product/nsc-373-chain-of-custody-standard

[60] FSC Standard for Chain of Custody Certification. Available at: https://connect.fsc.org/document-centre/documents/resource/302

3. Task 2: Market analysis and considerations

Eurostat data

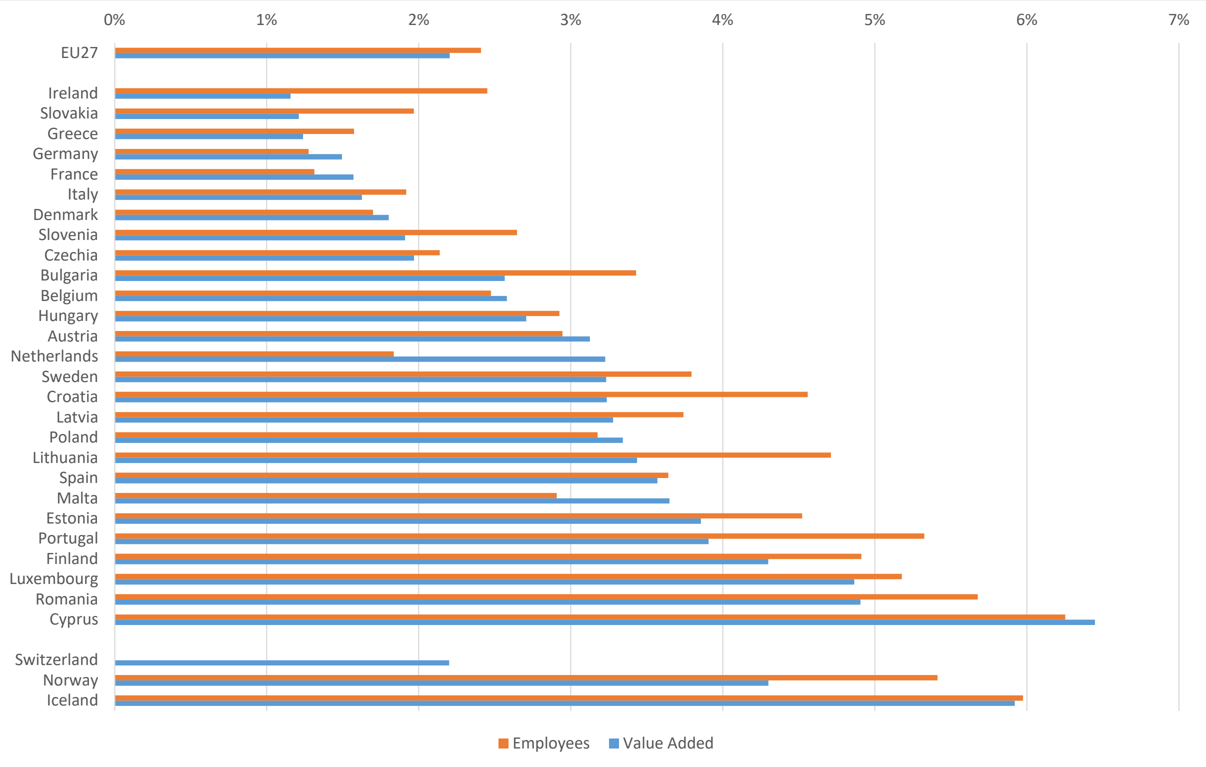
According to the Eurostat database for structural business statistics, the "EU construction of buildings" sector (corresponding to NACE Division 41, and further subdivided into "41.1: development of building projects" and "41.2: construction of residential and non-residential buildings") in 2020 accounted for the following:

- 862 950 enterprises (3.7% of all enterprises in the non-financial business economy[61] of the EU).
- Around 93.8% of these enterprises were micro-enterprises (<10 employees) and accounted for 46% of employment and 33.7% of value added.
- Only 1 886 (0.05%) enterprises employed more than 250 people in this sector, but they accounted for 12.9% of employment and 20.7% of value added.
- 2.6 million employees (2.4% of all employment in the non-financial business economy and 25.9% of the total number of people employed in construction).
- By comparing total employees with value added for the two subsectors in this activity, the apparent labour productivity for "41.1 development of building projects" was EUR 91 400/person while that of "41.2 construction of residential and non-residential buildings" was much lower, at EUR 39 400/person).

The percentage shares of value added and employment at Member State level are presented below, in order of value added.

[61] The non-financial business economy includes the sectors of industry, construction, distributive trades and services. This refers to economic activities covered by Sections B to J and L to N and Division 95 of NACE Rev. 2 and the enterprises or its legal units that carry out those activities. (B: Mining and quarrying; C: Manufacturing; D: Electricity, gas, steam and air-conditioning supply; E: Water supply; sewerage, waste management and remediation activities; **F: Construction;** G: Wholesale and retail trade; repair of motor vehicles and motorcycles; H: Transportation and storage; I: Accommodation and food service activities; J: Information and communication; L: Real estate activities; M: Professional, scientific and technical activities; N: Administrative and support service activities; 95: Repair of computers and personal and household goods).

Figure 9. Relative importance (%) of construction of buildings (NACE Division 41) at Member State level and the EU, 2020



Source: Eurostat (online data code sbs_na_sca_r2).

The data for "construction of buildings" include the construction of complete buildings for sale or ownership and includes remodelling or renovation of existing structures but does not include architectural, engineering, technical testing and analytical services (NACE Division 71). At national level, it must be noted that the building construction sector displays a strongly cyclical pattern that is influenced by business and consumer trust, interest rates and government programmes. It remains to be seen how the COVID pandemic and the injection of public finance into the building construction sector, coupled with major losses in other sectors related to tourism, will influence data for 2020 onwards.

The range of relative contributions of the construction of buildings to national economies shown in **Figure 9** varied between 1.2% and 6.4%. The average of the national contribution was 3%, while the share in the whole EU-27 was 2.2%. The building construction sectors in Cyprus and Romania were the most significant ones. While Germany had one of the least significant sectors at Member State level in relative terms, it is worth noting that it is by far the largest country in absolute numbers.

In terms of employment, the share of the sector ranged from 1.3% to 6.3% among the Member States, accounting for 2.4% of the employment of the whole EU-27. Again, Cyprus accounted for the highest contribution, while the lowest shares were those in France and Germany despite presenting the largest absolute values.

- To obtain an idea of the relevance of public contracts, a detailed search history of public authority contracts in Europe published in eTED shows that:4 043 contracts on 45100000 – "Site preparation work" were published from October 2016 to August 2023;
- 5 850 contracts on 45210000 – "Building construction work" were published from June 2017 to August 2023;
- 4 451 contracts on 45260000 – "Roof works and other special trade construction works" were published from September 2016 to August 2023;

- 8 623 contracts on 45300000 – "Building installation work" were published from February 2016 to August 2023;
- 5 985 contracts on 45400000 – "Building completion work" were published from November 2016 to August 2023;
- 719 contracts on 71221000 – "Architectural services for buildings" were published from August 2018 to August 2023;
- 1 712 contracts on 71500000 – "Construction-related services" were published from June 2016 to August 2023.

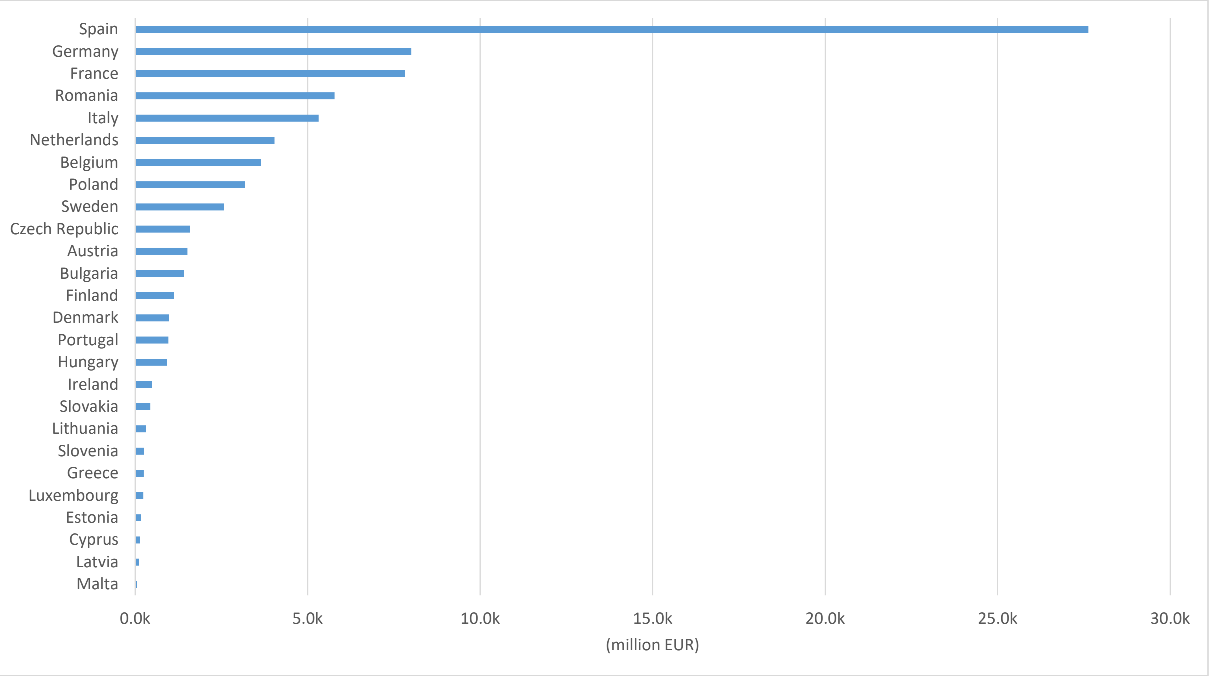
The European Construction Sector Observatory (ECSO)

The ECSO offers a wealth of information and analyses about the European construction sector, with particular focus on the five areas that were identified as part of an EU strategy for the sustainable competitiveness of the construction sector and its enterprises (see (COM 2012)433):

1. Financing and digitalisation
2. Skills and qualifications
3. Resource efficiency
4. Regulatory framework
5. International competition

The database shows how the investments by the construction sector increased in most of the Member States between 2011 and 2019, with annual growth rates even over 25% in Spain and Ireland. In absolute terms (Figure 10), Spain presented the highest investment (EUR 27.6 billion in 2019), while Malta showed the lowest investment (EUR 57.8 million in 2019), with the rest of the countries around the EUR 3 billion mark.

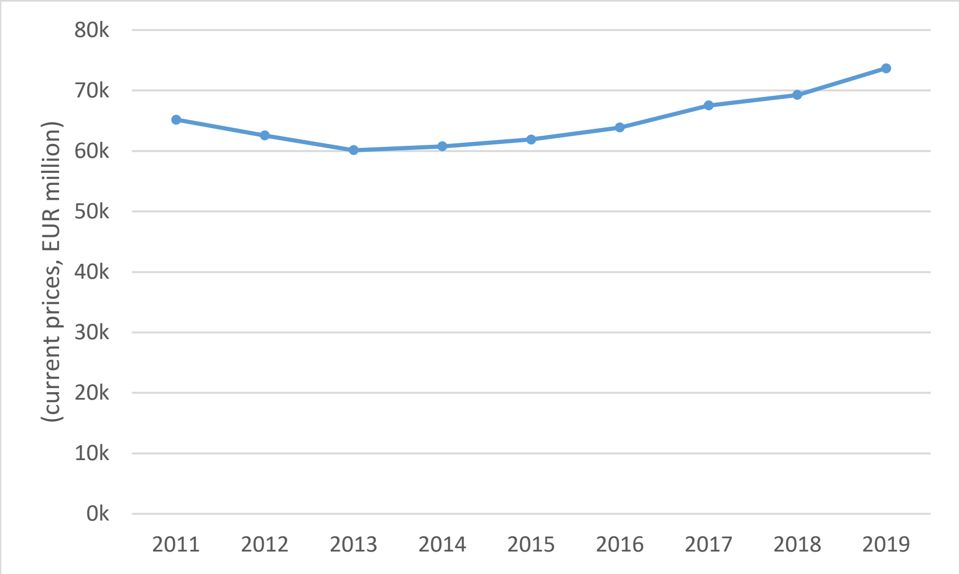
Figure 10. Investment in the construction industry (Gross fixed capital formation, total fixed assets), 2019



Source: European Construction Sector Observatory (ECSO), 2023. Available at: https://single-market-economy.ec.europa.eu/sectors/construction/observatory_en

Renovation spending also increased in the EU as a whole, with the Final consumption expenditure of households on maintenance and repair of dwellings being EUR 74 billion in 2019, and growing at a 3.4% annual rate since 2013 (Figure 11).

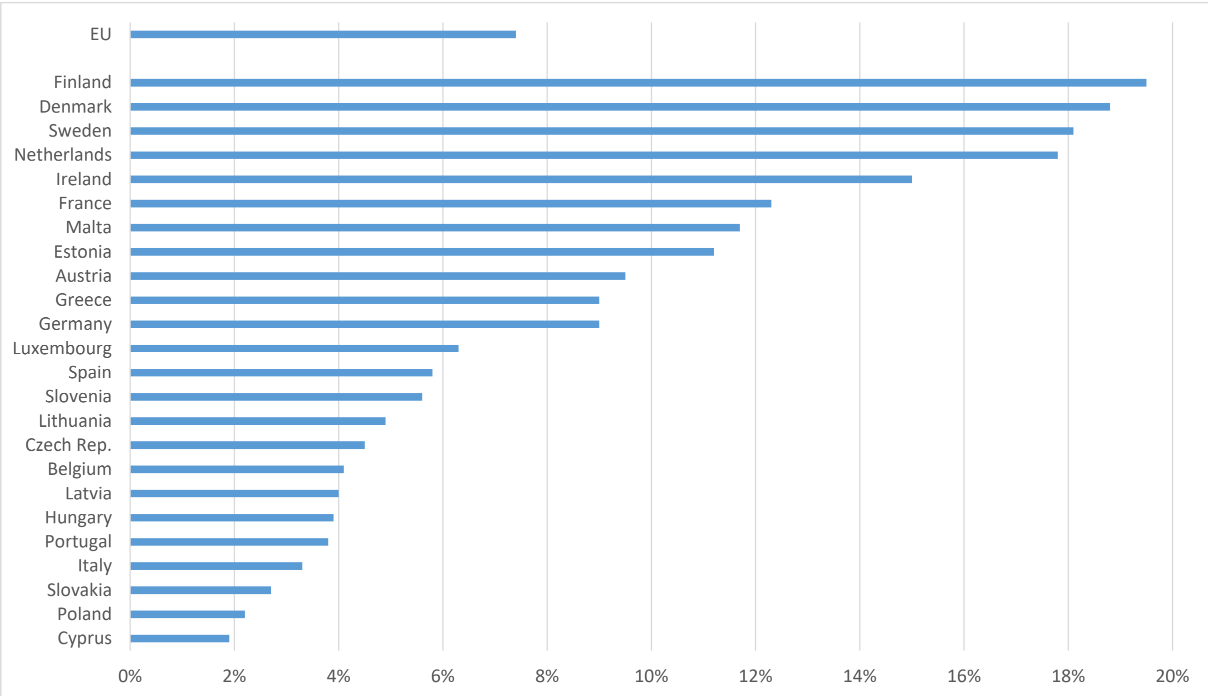
Figure 11. Final consumption expenditure of households on maintenance and repair of dwellings



Source: European Construction Sector Observatory (ECSO), 2023. Available at: https://single-market-economy.ec.europa.eu/sectors/construction/observatory_en

As for the education and skills in the sector (Figure 12), the figures show low participation in training, with levels below 20% in every Member State. The highest levels of participation were found in northern countries (Finland 19.5%, Denmark 18.8% and Sweden 18.1%) and the lowest in Cyprus and Poland (around 3%), being 7.4% for the whole EU in 2020.

Figure 12. Participation in education and training of adults in the construction sector, 2020



Source: European Construction Sector Observatory (ECSO), 2023. Available at: https://single-market-economy.ec.europa.eu/sectors/construction/observatory_en

European Building Stock Observatory (BSO)

The EU Building Stock Observatory (BSO) was established in 2016 with the aim to provide a better understanding of the energy performance of the building sector through reliable, consistent and comparable data.

The BSO contains a database, a data mapper and factsheets for monitoring the energy performance of buildings across Europe. The recast of the Energy Performance of Buildings Directive make direct reference to the requirement for Member States to provide data to the BSO in a standardised format each year.

The BSO covers a broad range of energy-related topics and provides information on the building stock, energy consumption, building elements and technical building systems installed, energy performance certificates, Nearly Zero-Energy Buildings and renovation rates, but also areas like energy poverty and financing aspects.

At the time of performing this study, a total of 250 indicators feed into the BSO database that cover the following 10 thematic areas:

- building stock characteristics;
- building shell performance;
- technical building systems;
- Nearly Zero-Energy Buildings;
- building renovation;
- energy consumption;
- certification;
- financing;
- energy poverty;
- energy market.

In 2024, an updated version of the database was launched, offering an improved user interface and better data availability (additional indicators and higher level of detail). For instance, information about occupancy, tenancy type and social aspects related to energy poverty have been included. Nevertheless, this report refers to the previous 2023 version, which was available at the time of performing the assessment that supported the development of the criteria of the EU GPP for buildings.

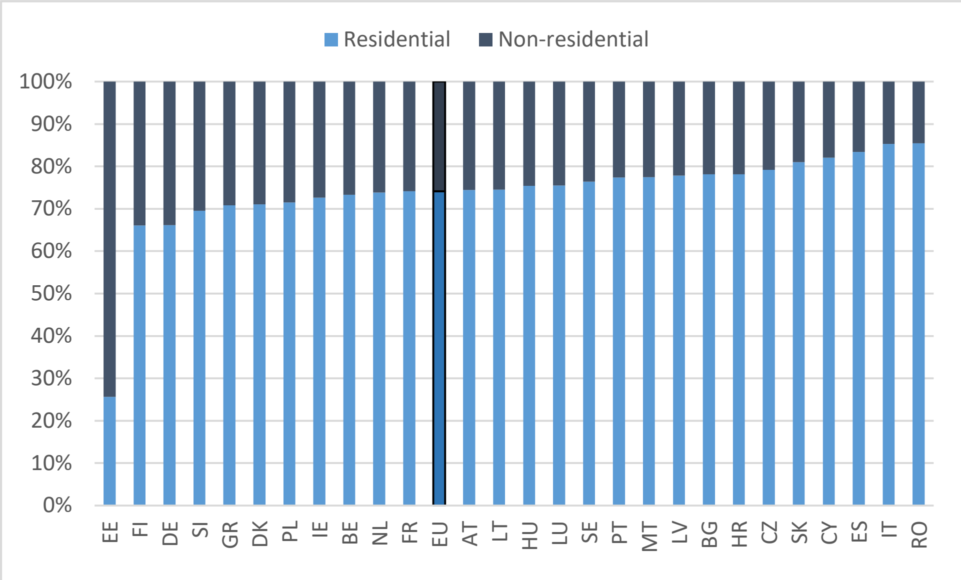
More specific aspects of the data from the BSO will be considered when investigating the technical improvement potential (Task 4) of energy efficiency and to place any concrete proposals for EU GPP criteria in the context of the existing building stock (in Task 5). For the sake of a general market overview, building stock characteristics from the BSO database and factsheets are considered here in Task 2, completed with data from other sources of interest when relevant, such as Odyssee and Housing Europe Observatory.

Building stock characteristics

Residential vs non-residential: the BSO splits residential buildings into the following categories:

- Residential: single family (detached, semi-detached) or multi-family;
- Non-residential: offices (private or public); wholesale and retail trade; hotels and restaurants; health care or educational buildings.

Figure 13. Split of residential and non-residential building floor areas, 2020 (except EU and Hungary (2016), Croatia (2018) and Sweden (2019))

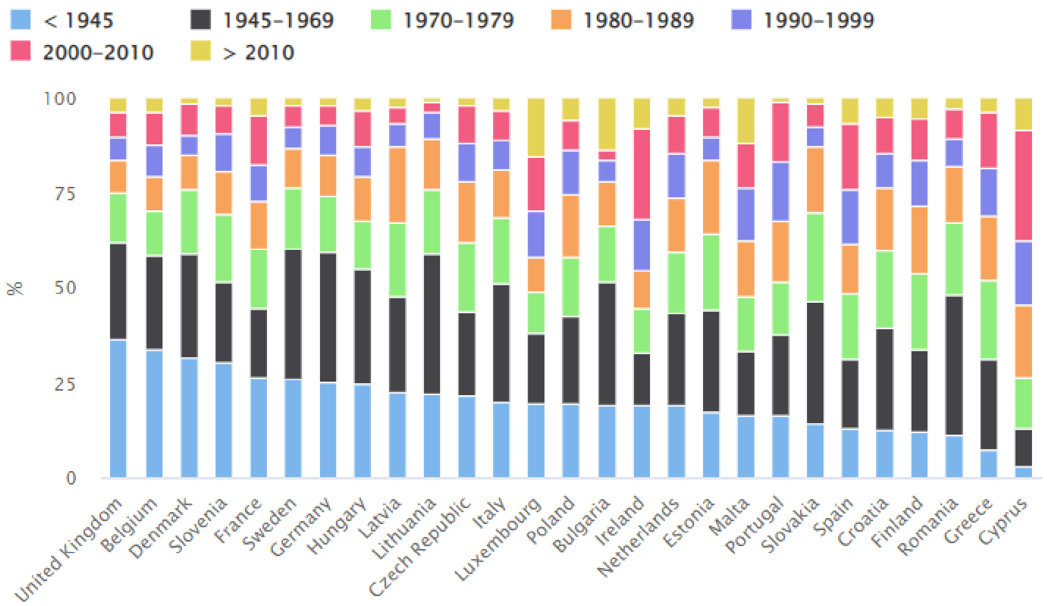


Source: Building Stock Observatory (BSO), 2023. Available at: https://building-stock-observatory.energy.ec.europa.eu/database/

The total floor area of buildings in the EU is dominated by residential buildings (around 74%), varying from as high as 85% in Romania to just 26% in Estonia (Figure 13).

Age profiles of residential buildings: The age profile of the residential building stock in different European countries is shown below.

Figure 14. Age profiles of residential buildings in different countries, 2012



Source: Building Stock Observatory factsheets, https://ec.europa.eu/energy/eu-buildings-factsheets_en?redir=1

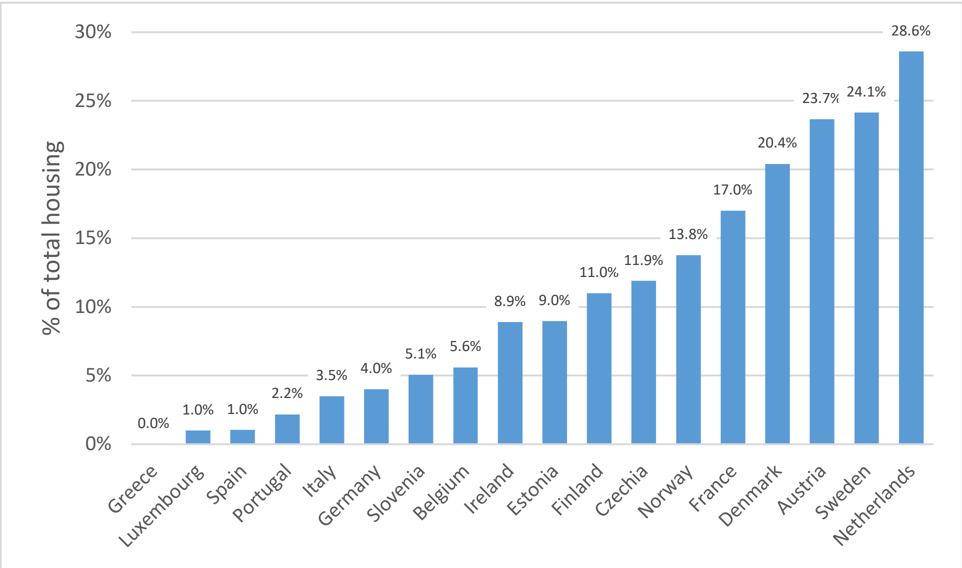
The data are ordered from left to right in order of the largest share of oldest buildings (<1945). With the notable exception of Cyprus, somewhere between 30% and 60% of all residential buildings standing in 2012 were built before the first thermal regulations for buildings came into force in 1970.

The countries with the most modern buildings (i.e. from the year 2000 onwards) are Cyprus, Luxembourg and Ireland with around 30% of buildings in this age category. Some countries only have very small shares of modern residential buildings in their stock (e.g. Lithuania at 3.5%; Latvia at 6.6%; Germany at 7.1%; Sweden at 7.2% and Slovakia at 7.3%).

Share of social housing: Social housing can be considered as housing that is provided at prices below normal market rates to target groups of disadvantaged people, socially less advantaged people or key workers.

Although residential buildings are mostly privately owned, it is worth paying attention to the share of residential buildings that are social housing in different countries, since it is likely that public finance will be directly or indirectly involved in the construction, renovation and management of such buildings.

Figure 15. Share of social housing in national housing building stocks. Latest year available by country (2019 - 2023)

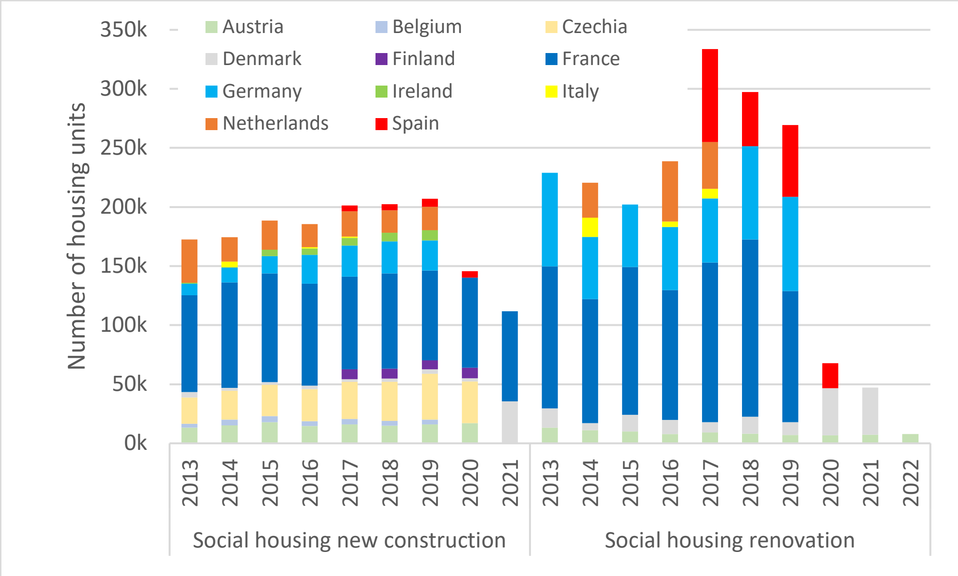


Source: Housing Europe Observatory. Housing Europe, 2021; Housing Europe, 2023.

The data from the Housing Europe report show a major difference in the proportions of housing stock that are considered as "social housing" in each country. There is a factor of 29 difference between the highest and lowest shares and there is a gradual spread of social housing shares for different countries in between. Generally speaking, the Nordic countries tend to present the highest shares of social housing, while the southern European countries show the lowest ones.

In terms of new construction and renovation of social housing units, the data shown in the figure below is presented in the Housing Europe report.

Figure 16. Trends in social housing construction and renovation in Europe (2013 to 2022, subject to data availability)



Source: Housing Europe Observatory. Housing Europe, 2021; Housing Europe, 2023.

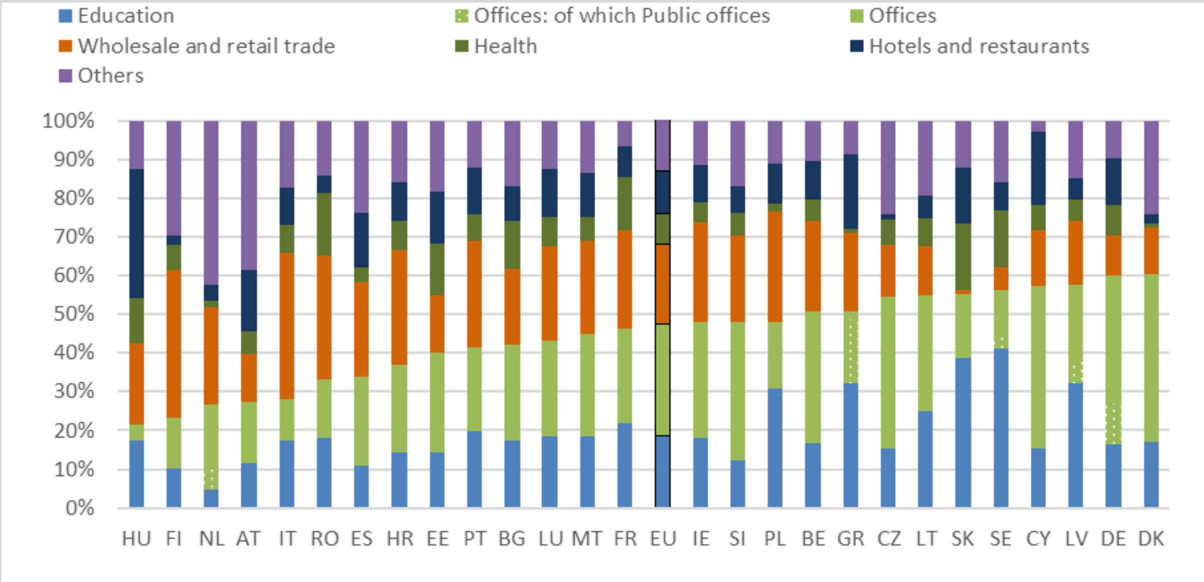
The data above, covering a limited number of Member States, show that construction and renovation activity for social housing varies significantly in different countries. Part of the difference may stem from the different policies and definitions used at national level. For example, whether housing is owned by public authorities, by not-for-profit housing associations or is made available for purchase and lower-than-market prices rather than rent.

Up until 2020, France was by far the leading Member State both in terms of new construction and renovation of social housing in terms of housing units. Germany (renovation and construction) and Spain (renovation) have significant shares of social housing activities; however, it should be borne in mind that these are also large Member States in terms of population. On the contrary, those Member States showing a proportionally high degree of activity in social housing construction and/or renovation during 2013 to 2020 are Austria, the Czech Republic and the Netherlands.

Note that data for most countries are not available from 2020 onwards, so lower totals in the following years do not mean a reduction in rates overall, but incomplete information.

Non-residential building types by floor area: The main building types of relevance to the EU GPP criteria are public offices and educational buildings.

Figure 17. Split of floor area by non-residential building type, 2020 (except Croatia (2018) and Hungary (2016)). EU figures exclude Croatia and Hungary



Source: Elaborated from Building Stock Observatory (BSO) and Odyssee, 2023. Available at: https://building-stock-observatory.energy.ec.europa.eu/database/ and https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

The share of public offices is only available for a few countries and varies significantly, most of them ranging between 5% and 10% of the total non-residential floor area, with Greece being the highest (16%) and Sweden the lowest (3%) in 2020. Generally, public offices represented around 23% of the offices floor space, except in Greece, where they reached almost 90%.

In terms of educational buildings, Sweden and Slovakia had the largest share at around 40% of total non-residential building floor area. Most countries had a share of between 15% and 20%, with the lowest shares in Finland (10%) and the Netherlands (5%).

With all the above, regulating public offices and educational buildings would mean targeting from 10% (in the Netherlands) to 50% (in Greece) of non-residential buildings.

Green Building Rating Systems (GBRSs)

Another important market development in the building sector which is considered of relevance in the revision of EU GPP criteria is the rise of Green Building Rating Systems (GBRSs). The idea of these systems is to score the “greenness” of a building design and/or a constructed building using a combination of mandatory and optional criteria. While the focus is normally on environmental aspects, it is also possible that criteria relate to social, economic and management aspects as well (directly or indirectly).

There are dozens of GBRSs worldwide (Sánchez Cordero, Gómez Melgar, and Andújar Márquez, 2019) with some of the most significant ones in Europe being:

- BREEAM (Building Research Establishment’s Environmental Assessment Method, since 1990);
- DGNB (Deutsche Gesellschaft Fur Nachhaltiges Bauen / The German Sustainable Building Council, since 2008);
- HQE (Haute Qualite Environment, since 1997);
- HQM (Home Quality Mark, since 2015);

- LEED (Leadership in Energy and Environmental Design);
- BEAT (Building Evaluation Assessment Tool, in Denmark);
- PromisE (The Finnish Environmental Performance Assessment Criteria);
- SBTool (IISBE, International Initiative for a Sustainable Built Environment).

The potential of GBRSs to drive market demand for “green” buildings is based on the availability of clearly defined technical criteria and associated scoring rules, together with benchmark scores that would be needed to certify a building as, for example, a bronze, silver or gold certified building.

Clients would tend to specify a desired final certification outcome as part of their brief to the design team, together with all the usual technical and functional requirements for the building. Then it would be up to the design team to work with a GBRS assessor to determine how they can achieve sufficient points to meet the rating. Because there are many different ways to achieve the certification, the GBRSs do not necessarily impact on the design freedoms to the point of compromising the original client brief.

Each GBRS has its own style, content and structure. According to Sánchez Cordero, Gómez Melgar, and Andújar Márquez (2019), there are more than 500 different indicators across dozens of GBRSs that can be applied to buildings in the EU. To ensure that GBRSs used in the EU can find, maintain or increase common ground, Level(s), a common EU framework for the assessment of the sustainability of buildings was developed by the European Commission. The first public version of Level(s) was released in October 2020, after a 2-year test phase.

The GBRSs have had time to start thinking about how to find common approaches with Level(s) and several of them are working on alignment.

In terms of certified buildings in the EU, Sánchez Cordero, Gómez Melgar, and Andújar Márquez (2019) indicate that BREEAM is by far the most commonly used, accounting for around 65% of the 11 000+ certified buildings in the EU considered in their study.

The study from Sánchez Cordero, Gómez Melgar, and Andújar Márquez, 2019 showed high-level overlaps between Level(s) macro-objectives, selected GBRS and the EU GPP criteria for office buildings from 2016 (see Annex III).

4. Task 3: Identification of main environmental impacts associated with buildings

Many of the environmental impacts of buildings can, and have been, assessed by Life Cycle Assessment methodologies. These methods can quantify a significant number of different midpoint environmental impacts, the most commonly assessed of which is Global Warming Potential.

However, because a number of environmental impacts are not well covered by LCA methods, in addition to a review of the LCA literature, other environmental impacts will also be considered.

Site selection

The first strategic decision taken when deciding on client needs for a new building is the choice of building site. This could be a greenfield site, an urban site or the site of an existing building (including the further choice about whether to demolish and rebuild or to renovate). Some of the potential environmental impacts and benefits for these four different scenarios are as follows.

Table 6. Potential impacts and benefits based on building project type

Project type	Negative impacts	Positive impacts
New building on greenfield site	• Significant disruption to topsoil and any flora and fauna on site and in immediate surroundings during construction and during building lifetime. • Will normally increase storm water runoff rates → increased flood risks downstream. • Additional materials and resources used to connect to services and other infrastructure. • If very remote, need to discharge wastewater locally. • Possible need for building users to travel further or by private car to access building.	• Less space/access restrictions. • Less interference from existing services and infrastructure. • Reincorporation of topsoil and excavation waste on site or nearby. • Incorporate sustainable drainage features for the plot area. • Well-designed landscaping and introduction of green roof/walls, nesting boxes and water features.
New building on empty urban plot	• Disruption to any topsoil and any flora or fauna on the plot area during construction and during building lifetime. • Depending on site history, possibility of contaminated soil to be treated.	• Potential mitigation via landscaping and introduction of green roof/walls, nesting boxes and water features. • Cleaning of any contaminated soil. • Can expect good existing public transport links and amenities for building users.
Demolition of existing building and later construction on same plot	• Production of large quantities of Demolition Waste (DW), including hazardous waste. • More materials needed for new building than if choosing to renovate instead. • Space and access restrictions → safety concerns and need to transport/store waste off site. • Care needed not to disrupt existing services and infrastructure.	• Opportunities for reusing, recycling and recovering materials and components. • Greater design freedom for new building than if choosing to renovate.
Major renovation of existing building.	• Space and access restrictions → safety concerns and need to transport/store waste off site.	• Material efficiency by reusing the existing structure and any other building elements.

	• Limited scope for new building features, functionality and performance.	

Source: author's own elaboration.

There are many factors that can influence the choice of site for a public building project; these decisions could already have been taken as part of much broader urban planning strategies, or be due to economic factors, the preference of future occupants of the building or other sites being ruled out due to conflicts with surrounding landowners.

Whatever the reasoning behind the choice of the site, in cases where a new building is to be constructed on a greenfield site, some mandatory requirements relating to biodiversity mitigation should apply – with the aim of restoring or, even better, enhancing the biodiversity of the site after the new building has been constructed.

Life Cycle Assessment of buildings

General methodology and related issues

The five most commonly tracked environmental impact categories in Life Cycle Assessment for buildings are Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Eutrophication Potential (EP), Acidification Potential (AP), and Smog Formation Potential (SFP) (The Carbon Leadership Forum, 2019). However, of all the LCA indicators, by far the most widely used and reported on is Global Warming Potential (GWP) and for this reason, the main focus of this chapter is on GWP assessments of buildings.

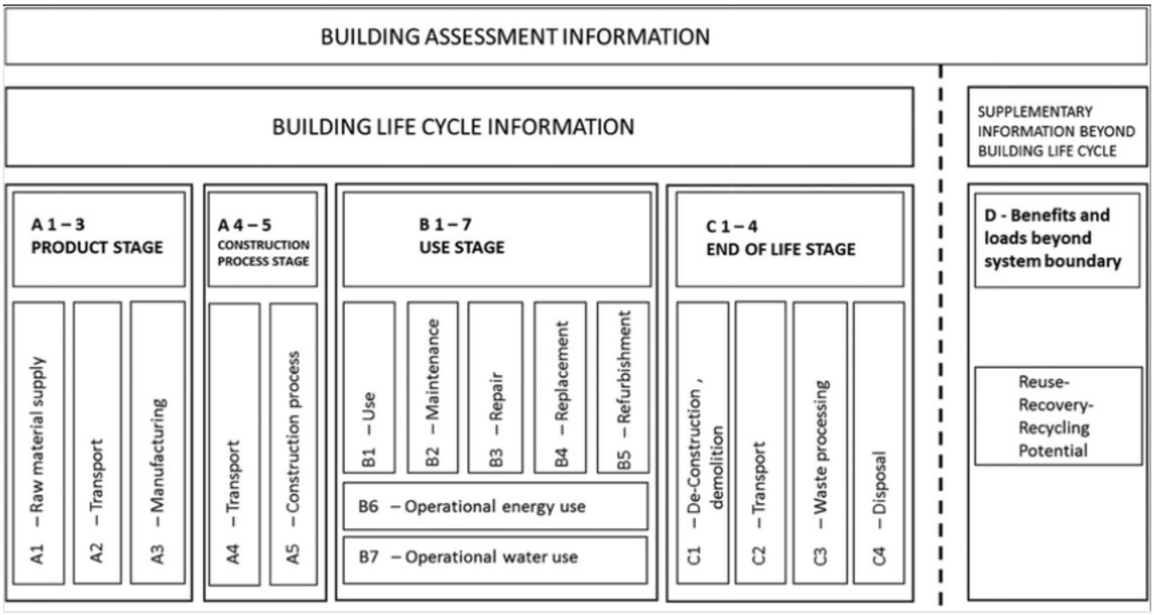
It is widely reported that European buildings are associated with around 36% of total operational CO_2 emissions in Europe[62]. With policy targeting a climate-neutral Europe by 2050 and buildings being responsible for such a significant share of greenhouse gas emissions, a lot of focus has been placed on life cycle carbon emissions in the academic literature and in real-life building projects.

The environmental impact of the built environment needs to be reduced substantially and LCA is an internationally accepted methodology to assist in this aim. In fact, over the last decades, LCA has evolved significantly into a refined assessment procedure used for efficient environmental designs, to strengthen the decision-making process in the built environment (Amarasinghe and Hadiwattege, 2020). LCAs, standardised by the international norms ISO 14040:2006 and ISO 14044:2006+A1:2018 at a general level and by the European standard EN 15978:2011 at the building level, have proved to be a robust method to evaluate the environmental effects of construction products and materials, as well as whole buildings along their life cycle (Del Rosario, Palumbo, and Traverso, 2021).

In Europe, the EN 15978 standard provides the common definition for the different life cycle stages of a building (**Figure 18**).

[62] https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en

Figure 18. Display of modular information for the different stages of the building assessment



Source: EN 15978:2011. Sustainability of Construction Works – Assessment of environmental performance of buildings – Calculation method.

The framework does not include site preparation (essentially module A0). While the EN 15978 standard forms the basis for the LCA of buildings in Europe, there are areas of freedom for LCA practitioners, necessary to one extent or another, that thus represent sources of major variations in results and that would need to be harmonised in order to make the results of different buildings truly comparable. For example, Nwodo and Anumba (2019) identified the following sources of variation:

- data intensity and quality;
- definition of functional units;
- assumptions for building life span and building element service lives;
- lack of procedures for defining system boundaries;
- lack of uncertainty analysis.

Björklund, 2002 also presented and discussed a number of types of uncertainty with LCA studies and the lack of uncertainty analysis in building LCA studies was also cited as a concern by Pomponi, D'Amico, and Moncaster, (2017) who pointed to the potential of Monte Carlo algorithms as a relatively simple way of incorporating uncertainty analysis in building LCA studies.

A lot of research has been published for life cycle GWP of residential buildings, which is well justified since they account for around 75% of total EU building stock. Chastas et al., (2018) reviewed a total of 95 LCA studies of residential buildings. They tried to make the results more comparable by normalising the reference study periods to 50 years (71 of the 95 studies had already used 50 years) and then filtering out studies that (i) did not clearly define the floor area, or (ii) did not clearly show that A4+A5 life cycle stages were included, or (iii) did not cover all of the main sources of operational energy consumption (i.e. heating, ventilation, cooling, domestic hot water, lighting and appliances). The authors found that the share of embodied carbon increases as the energy performance of the building increases; more specifically, shares of embodied carbon were from 9% to 22% for conventional residential buildings, from 32% to 38% for passive houses and from 21% to 57% for low-energy residential buildings. A NZEB building that did not pass the filtering criteria had embodied carbon accounting for 71% of total life cycle carbon.

In a review of case studies of single family houses, Soust-Verdaguer, Llatas, and García-Martínez (2016) reported that there was significant heterogeneity in LCA studies for residential buildings in the literature. Some of the main differences were as follows:

- Different goals for the studies (e.g. to compare different building designs, to optimise a single design, a sensitivity analysis for specific features, such as the energy mix).
- Different scopes for the studies (e.g. different life cycle stages included/excluded, different functional units used, including/excluding interior fittings and services in embodied carbon analysis).
- Different assumptions for building reference lifetime, different assumptions for service lives of building elements and different end-of-life assumptions.

Schools and many educational buildings are typically low-rise buildings within a significant plot area and thus have quite a high specific envelope area to interior volume ratio. This can make these buildings more susceptible to heat loss, or excessive solar gain in cases of poor envelope thermal performance. However, at the same time, these types of buildings have significant opportunities to improve energy efficiency and reduce the carbon emissions, especially via the installation of combined heat and power units and the installation of on-site renewable energy systems.

Variability in studies due to different scopes for operational energy (module B6)

Results from different studies are not easy to compare for a number of reasons, one of which is differences in the precise scope of operational energy consumption in module B6, which can differ as follows:

- including some or all of five main building technical systems covered by the Energy Performance of Buildings Directive (heating, ventilation, cooling, hot water and lighting systems);
- including other building systems (e.g. lifts and escalators);
- including non-building-related uses (e.g. plug-in devices, appliances or even vehicle charging);
- including (i.e. subtracting) exporting energy from on-site renewable energy systems.

Variability in studies due to different scopes for embodied carbon (modules A1-A5 and B2 to B4)

While building designers will have a much clearer idea of the quantities of materials involved in the sub-structure and superstructure (because these need to be accurately specified and because relatively few materials and components are involved), gathering data for “interior fittings” and “building services” is a much more onerous task.

A recent study by the Concrete Centre (2022) found that building services (such as heating, ventilation and air-conditioning systems) accounted for around a third of embodied carbon in a concrete apartment block (with the structure accounting for another third and cladding and internal floors and walls accounting for the final third).

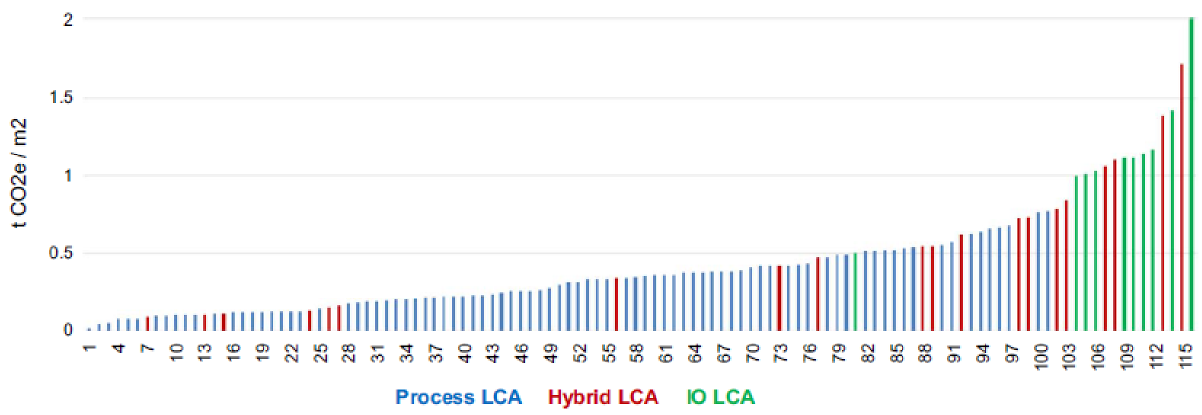
A design guide published by the London Energy Transition Initiative (LETI CEDG, 2020) estimated that mechanical, electrical and public health services (MEP) and internal finishes accounted for up to 35% of embodied carbon for office buildings (19%), residential buildings (20%) and school buildings (35%).

Therefore, it can be reasonably assumed that failing to report on building services and interior finishes can lead to significant underestimates of embodied carbon.

Variability caused by type of LCA method

Just looking at the pre-use phase (i.e. modules A1-A5), Säynäjoki et al., (2017) found that embodied carbon footprints varied by a factor of almost 70 (from 30 $kgCO_2.eq./m^2$ to 2 000 $kgCO_2.eq./m^2$). Such a large range of variation is a concern given that many of the other sources of variation, such as assumed service lives of building elements, assumed life of the entire building and operational energy performance, were not even considered. The full distribution of results from the 116 studies reviewed by the authors is shown below.

Figure 19. Greenhouse gas emissions per gross m² of building in LCA studies



Source: Säynäjoki et al., 2017.

The distribution of results shows some clear association between the nature of the LCA method and the final result, with "process LCA" studies dominating the lower range of results and "IO LCA" (Input-Output) studies dominating the higher range of results. Säynäjoki et al. (2017) explain the following:

- Process LCA methods are the most common and are based on energy and mass flows for all of the processes involved in making the building but can lead to underestimates when applying cut-off criteria at the level of each individual process.
- Input-Output LCA methods are based on monetary transactions that follow causal relationships between different industry sectors. These economic relationships are established in input-output tables for entire national or regional economies and provide overall relationships such as "X million EUR of steel is associated with Y tonnes of CO_2 emissions". However, this method also suffers from the limitation that the same economic relationship is assumed for all activities within a given sector, when this will often not be the case (e.g. not all steel is equal in terms of specific CO_2 emissions). This type of inaccuracy is known as an aggregation error.
- Hybrid LCAs attempt to combine the useful features of both types of LCA method.

The tendency for high values to be generated by IO LCA methods was also commented on by Rock et al. (2020), who highlighted this method as being more commonly applied in LCAs for office building studies in the US and Japan.

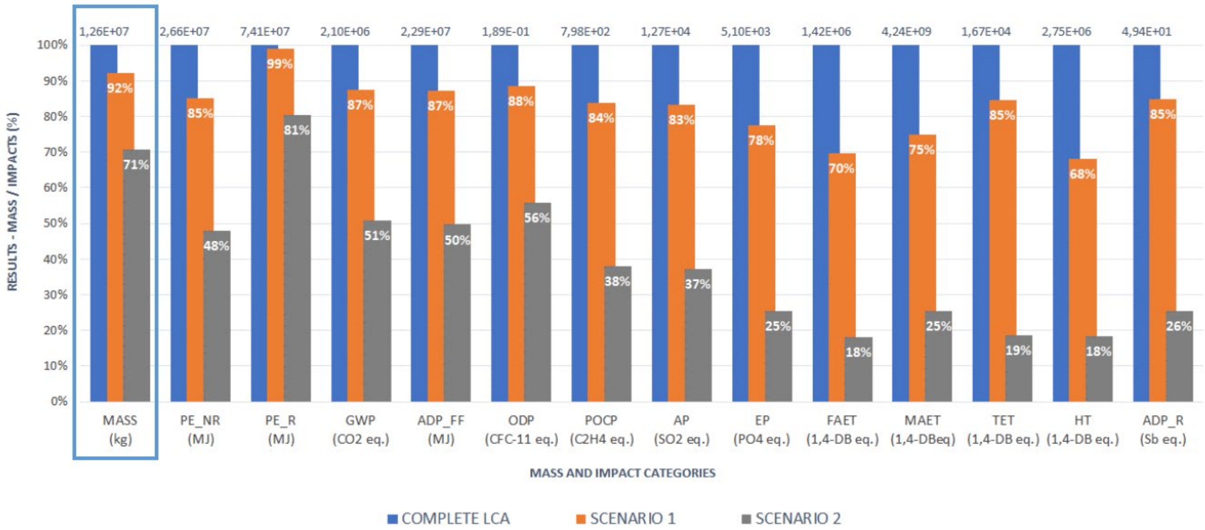
Variability caused by use of different cut-off rules

The effect of applying different cut-off rules on the results of a whole building LCA for (i) a standard design Brazilian public school building, (ii) a living laboratory and (iii) a passive office building showed that the choice of cut-off rules could significantly affect the total amounts of materials remaining in the LCA study and thus the results for different impact categories (Gomes Silva and Pulgrossi, 2020). The cut-off scenarios in question were as follows:

- Scenario 1: excluding items that represent less than 1% of total mass input or less than 1% of energy usage in unit processes (so long as all combined this does not exceed 5% of the total mass or energy (EN 15804:2012).
- Scenario 2: excluding all building elements except for the structure and envelope (LEED approach).

The authors found that the EN 15804 cut-off rule removed between 2% and 8% of the total mass to be assessed while the LEED cut-off rule removed increased these mass removals to between 29% and 32%. The effect on individual impact categories was often disproportionately higher than the mass removal (compare changes between blue, orange and grey columns for “Mass” with changes in the equivalent columns for other indicators in the figure below).

Figure 20. Comparative results for full assessment and 2 cut-off scenarios for a public school



Source: Gomes and Pulgrossi, 2020.

Some examples of disproportionate differences caused by the cut-off scenarios include:

- 8% of mass cut-off translating to a 13% drop in GWP and a 32% drop in Human Toxicity;
- 29% of mass cut-off translating to just a 19% drop in renewable primary energy but a 75% drop in Eutrophication Potential.

To help set greater commonality between assessments, the Level(s) framework provides detailed guidance for the use of cut-offs and the scope of life cycle stages. Moreover, it defines a minimum scope of building elements to be covered in life cycle carbon assessments in Level(s) user manual 1.2 that is much more comprehensive than just the building structure and envelope as specified in LEED. Furthermore, Level(s) also defines default service lives to be used for many building elements, which users should use in the absence of better estimations.

Table 7. Minimum scope for Level(s) building elements for life cycle GWP analysis

Building parts	Related building elements	Expected lifespan
Shell (substructure and superstructure)		
Load bearing structural frame	– Frame (beams, columns and slabs) – Upper floors – External walls – Balconies	60 years
Non-load bearing elements	– Ground floor slab – Internal walls, partitions and doors – Stairs and ramps	30 years
Facades	– External wall systems, cladding and shading devices	30 years (35 years glazed)

Building parts	Related building elements	Expected lifespan
	– Façade openings (including windows and external doors)	30 years
	– External paints, coatings and renders	10 years (paint), 30 years (render)
Roof	– Structure – Weatherproofing	30 years
Parking facilities	– Above ground and underground (within the curtilage of the building and servicing the building occupiers) [63]	60 years
Core (fittings, furnishings and services)		
Fittings and furnishings	– Sanitary fittings	20 years
	– Cupboards, wardrobes and worktops	10 years
	– Floor finishes, coverings and coatings	30 years (finishes), 10 years (coatings)
	– Skirting and trimming	30 years
	– Sockets and switches	30 years
	– Wall and ceiling finishes and coatings	20 years (finishes), 10 years (coatings)
In-built lighting system	– Light fittings – Control systems and sensors	15 years
Energy system	– Heating plant and distribution	20 years
	– Radiators	30 years
	– Cooling plant and distribution	15 years
	– Electricity generation	15 years
	– Electricity distribution	30 years
Ventilation system	– Air handling units	20 years
	– Ductwork and distribution	30 years
Sanitary systems	– Cold water distribution – Hot water distribution – Water treatment systems – Drainage system	25 years
Other systems	– Lifts and escalators	20 years
	– Firefighting installations	30 years
	– Communication and security installations	15 years
	– Telecoms and data installations	15 years
External works		
Utilities	– Connections and diversions – Substations and equipment	30 years
Landscaping	– Paving and other hard surfacing	25 years
	– Fencing, railings and walls	20 years
	– Drainage systems	30 years

Source: Level(s) user manual 1.2, available at the JRC website.

[63] If the share of underground car parking (usable area plus traffic area) accounts for more than 25% of the total useful floor area, the traffic area of the underground parking must be subtracted from the total useful floor area.

The need for better harmonisation between Product Environmental Footprint (PEF) and EN 15978

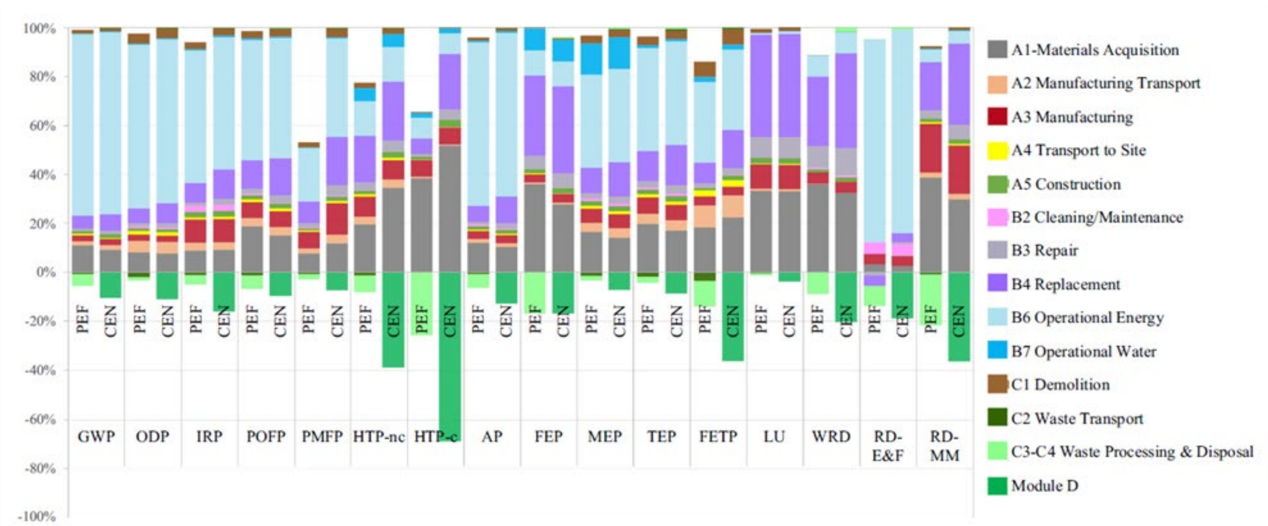
An analysis conducted by Mirzaie, Thuring, and Allacker (2020) whose main goal was to compare PEF and EN 15978 methods for end-of-life modelling and results for an office building also showed nicely in one graph how the different impact categories were compared along the life cycle phases from modules A to D of a building.

One important point of the paper was to emphasise the differences in module C and D results for the two methods. The authors identified the need to better harmonise the EN 15978 and PEF methods in terms of end-of-life formulas by (i) reporting module D like EN 15978 does and (ii) reporting burdens and benefits separately for each life cycle stage like PEF does. Without harmonisation on this approach, any LCA database will be compatible with one methodology or the other, limiting the scope for analysis of LCA practitioners in a given project. The need for harmonisation is especially pressing with the general shift that is happening from “zero-energy” buildings to “zero-emission” buildings.

As of early 2022, the European Commission has a new Recommendation in place (Recommendation 2021/2279[64], repealing the original PEF Recommendation 2013/179[65]). A total of four annexes come together with the new PEF Recommendation that provide details on the Life Cycle Assessment methodology, modelling requirements, data provision and data quality requirements. The EN 15978 standard was originally published in 2011 and it is not clear if and when the standard might be revised.

The data presented by Mirzaire et al. (2020) also give a good indication of when the main life cycle impacts occur for a building, both in relative terms per impact category and in weighted and normalised terms.

Figure 21. Relative comparison of life cycle impacts according to PEF and CEN (EN 15978) standards



Source: Mirzaie, Thuring, and Allacker, 2020.

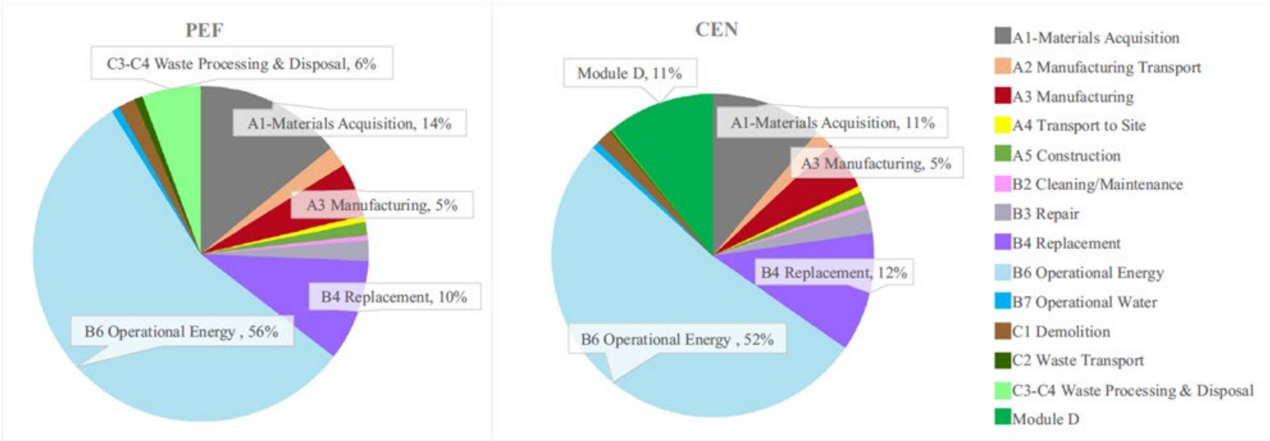
The data in **Figure 21** show how, for example, impacts like Global Warming Potential (GWP), Ozone Depletion Potential (ODP) and Acidification Potential (AP) and Resource Depletion of energy carriers and fossil fuels (RD-E&F) are dominated by operational energy. It also shows how the operational energy stage of the building life cycle has little to no influence at all on impacts such as Land Use

[64] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021H2279

[65] Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013H0179

(LU), Water Resource Depletion (WRD) and Resource Depletion of non-fossil minerals and metals (RD-MM).

Figure 22. Relative contributions of office building life cycle modules to the single score impact



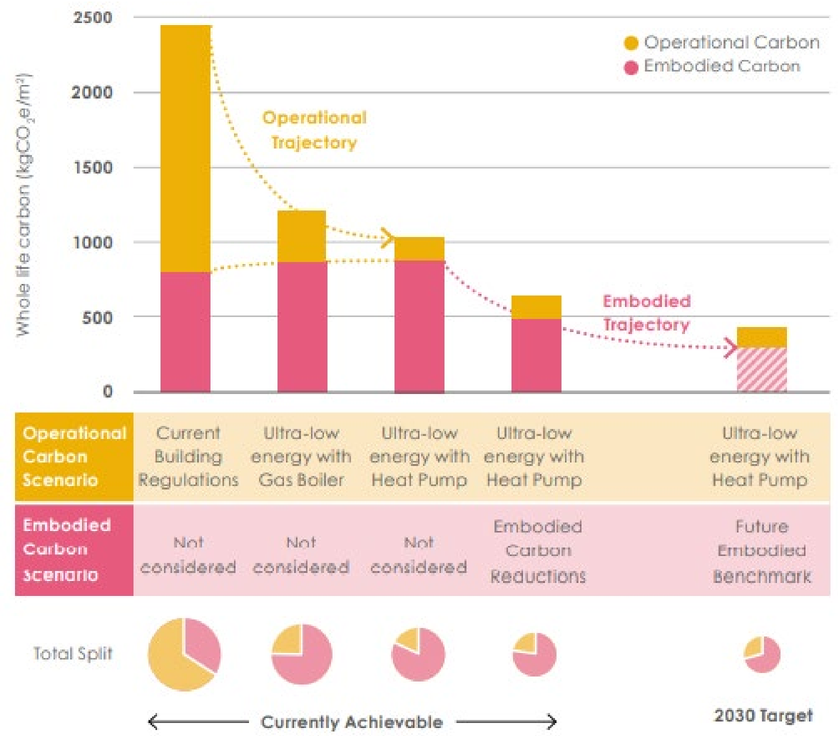
Source: Mirzaie, Thuring, and Allacker, 2020.

From **Figure 22** it is clear that after applying weighting factors to the results of the different impact categories shown in **Figure 21** to achieve a single score, operational energy is the most significant life cycle stage. Overall, the total impacts due to operational energy (i.e. B6) and total impacts due to materials (i.e. A1 to C4, excluding B6 and B7) were split almost 50:50.

Trends and relationships between operational and embodied carbon

With older buildings, operational carbon emissions would typically dominate the total carbon emissions over the full life cycle of a building. However, as designers chase zero-energy targets, which involves making buildings more energy-efficient and using lower carbon energy sources, the contribution of embodied carbon to whole life cycle carbon emissions becomes more and more significant. In terms of future scenarios, this trend is well illustrated in the Climate Emergency Design Guide (CEDG) published by the London Energy Transformation Initiative (LETI).

Figure 23. Projected operational and embodied carbon trajectories

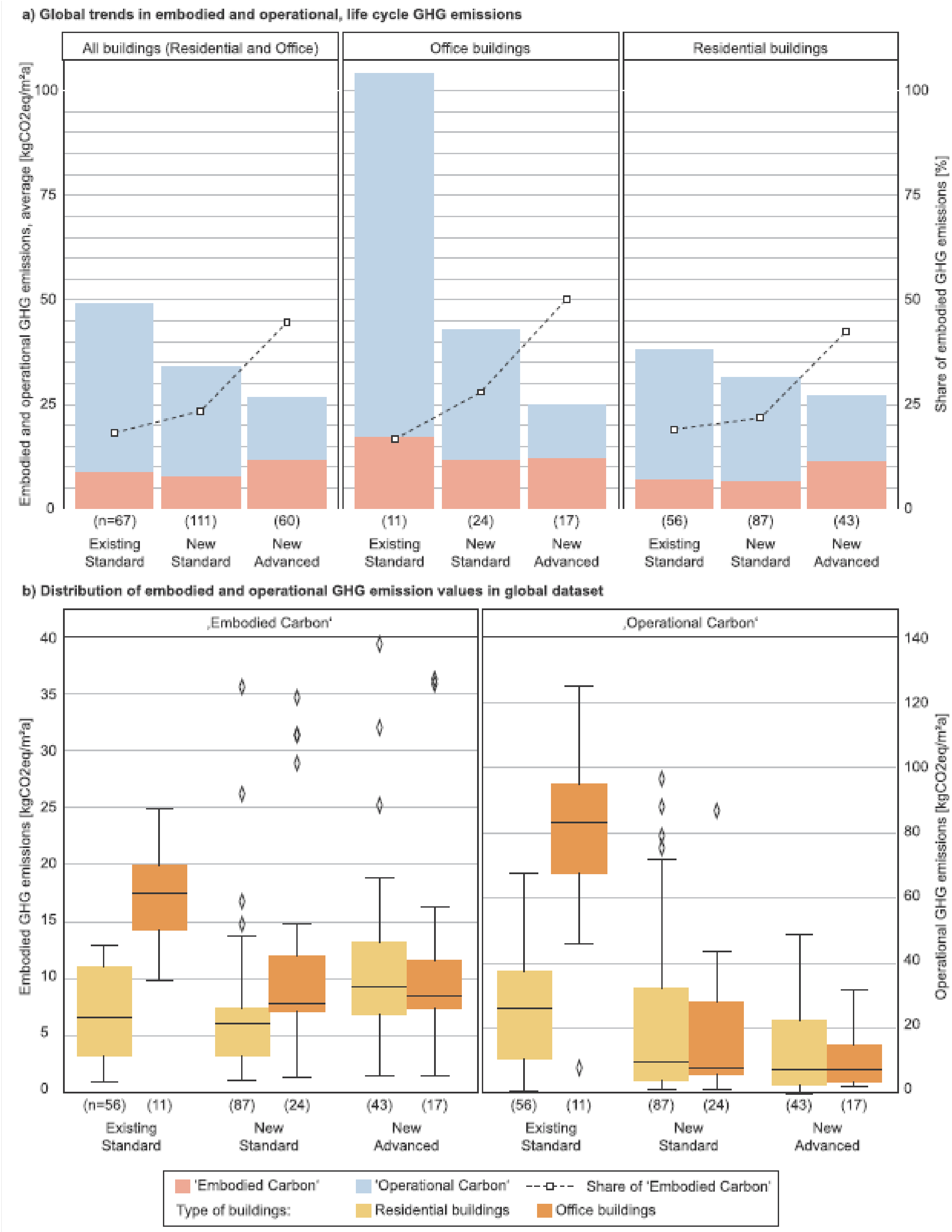


Source: LETI, CEDG, 2020.

The trends shown in the figure above (**Figure 23**) indicate a dramatic reduction in operational carbon being brought about by a shift to much more efficient heating technologies and a very modest increase in the embodied carbon occurring (e.g. via more insulation materials). Efforts to reduce embodied carbon, which would by then be the dominant source of overall carbon, could involve building using less materials, more durable materials and systems that are easier to repair, specifying low-carbon materials, the increased use of prefabricated elements and building spaces that are easy to adapt.

A similar trend of major reductions in operational carbon coupled with more modest reductions, or even increases, in embodied carbon was found by Röck et al., (2020) in a broad study of over 650 case studies.

Figure 24. (a) Average trends and (b) spread of individual values for life cycle carbon for residential and office buildings of different energy classes



Source: Röck et al., 2020.

A wealth of information is contained in the figure above. Results are split into three levels of energy performance category as follows:

- "Existing standard": i.e. buildings constructed before the tightening of standards for energy performance.
- "New standard": i.e. buildings constructed in line with recent or current building standards for energy performance.

- "New advanced": i.e. passive houses or near or net zero-energy buildings.

In Part (a) at the top of the graph, the average embodied and operational carbon impacts are stacked together. The first observation is that the combined trend for residential and office buildings is dominated by the trends for residential buildings, because the number of residential buildings in the final analysis was 3-4 times higher than office buildings. What can be seen from Part (a) of **Figure 24** is that there are highly significant reductions in operational carbon for both office and residential buildings (especially office buildings) as the energy performance standard applied to the building improves. Moving from "existing standard" to "new standard", embodied carbon did not increase in absolute terms, but it did increase significantly for residential buildings and slightly for office buildings when moving from "new standard" to "new advanced". These changes effectively meant the share of embodied carbon increasing from 17% to 28% to 50% for office buildings and from 19% to 22% to 43% for residential buildings when going from "existing standard" to "new standard" to "new advanced" building types.

In terms of the distribution of individual operational carbon and embodied carbon results, Part (b) of **Figure 24** shows box plots with the 1^{st} quartile and 3^{rd} quartile values (line in between being the 2^{nd} quartile value) and the ends of the whiskers representing maximum and minimum values. While the spread of results for each dataset was significant, focusing on median values shows clear trends and the box plots showed that "new advanced" residential buildings suffered from a much greater increase in embodied carbon than office buildings.

A typical scenario for how embodied and operational carbon emissions occur over a new building life cycle, also from the LETI design guide, is provided below.

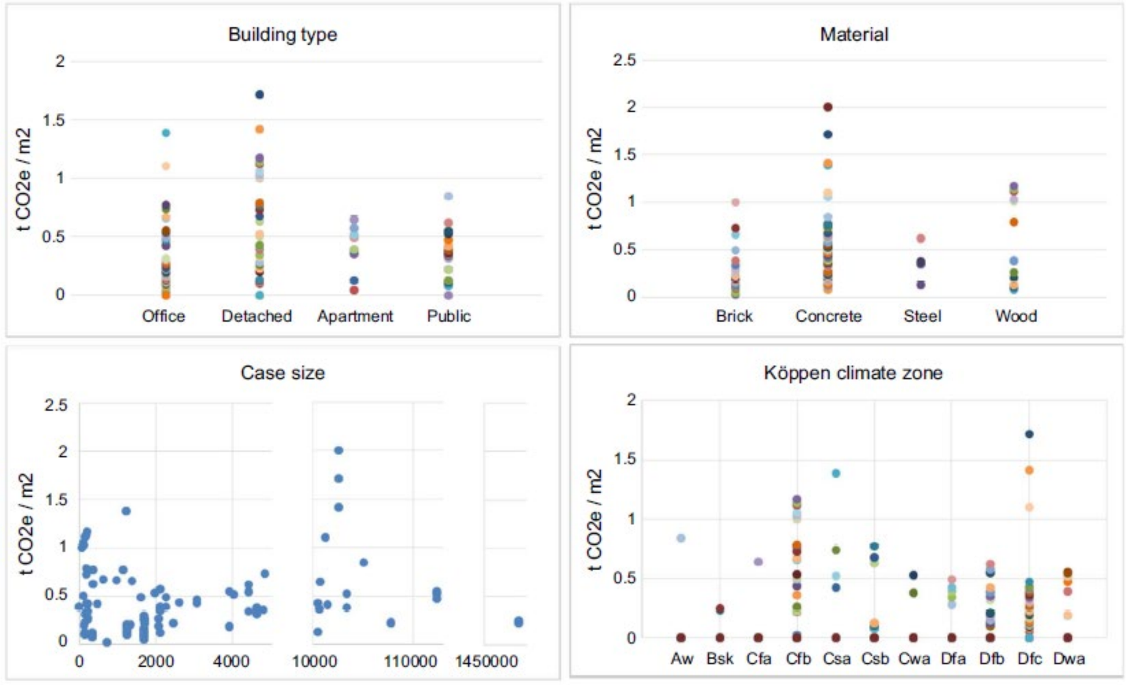
The LETI design guide actually promotes the separate reporting of embodied carbon because of the external influence on operational carbon of carbon factors of energy sources (e.g. Rasmussen, Harpa, and Birkved, 2013, or simply buying 100% renewable electricity from the grid would improve building results without any actions necessarily being taken by the building designer). So they promote targets for "Energy Use Intensity" (EUI) for all normal use phase energy consumption (except vehicle charging) in lieu of operational carbon and separate targets for embodied carbon. The targets they set are as follows:

- Small-scale housing: 35 non-renewable kWh/m^2.yr (15 due to space heating) and 500 $kgCO_2/m^2$.
- Medium- and large-scale housing: 35 non-renewable kWh/m^2.yr (15 due to space heating) and 500 $kgCO_2/m^2$.
- Commercial offices: 55 non-renewable kWh/m^2.yr (15 due to space heating) and 600 $kgCO_2/m^2$.
- Schools: 65 non-renewable kWh/m^2.yr (15 due to space heating) and 600 $kgCO_2/m^2$.

These embodied energy targets represent a 40% reduction compared to baseline scenarios. Ignoring any major design innovations, meeting these targets would generally require the greater incorporation of significant shares of reused materials in the building and a much greater reuse potential of building elements at end of life.

The study referred to earlier on the sensitivity of 116 as-constructed embodied carbon results for buildings (Säynäjoki et al., 2017) also compared results by building type, main structural material, building size and climate zone.

Figure 25. Plots of results of 116 case studies according to building type, materials, size and climate zone



Source: Säynäjoki et al., 2017.

From the results shown above, these factors still showed significant variability within each variable. Although no clear relationship could be established, it is interesting to see the following:

- that detached residential buildings tended towards higher embodied carbon results than apartment buildings;
- that public buildings (mainly educational buildings) had a similar spread of embodied carbon results as office buildings (ignoring some higher outliers for office buildings);
- that differences in the order of magnitude could be seen within the data sets for each building type;
- that wood materials did not show any clear benefits on embodied carbon compared to other materials;
- that there is no correlation between total building floor area and specific CO_2/m^2;
- that the climate zones do not explain the LCA difference in results as a pattern cannot be observed across the zones.

The dominant sources of variations in results between different studies appear to be method-based and data source-based. Consequently, before any policy might consider setting voluntary or mandatory targets for buildings, freedoms on the methodology must be tightened and the choice of generic data more limited.

Level(s)[15] is a tool that puts the whole life carbon principles into practice. The Level(s) framework emphasizes the importance of considering both, embodied and operational carbon to achieve low whole life carbon. It promotes design principles like adaptability, deconstruction, and material reuse to extend building lifespans and reduce overall carbon emissions. This holistic approach ensures sustainable building practices and resource conservation. Additionally, the Level(s) framework supports a life cycle perspective, treating buildings as repositories for carbon-intensive resources over decades. This approach encourages the use of cost-effective measures to reduce embodied carbon, which can yield greater performance improvements at a lower cost compared to focusing solely on operational carbon savings.

Non-Life Cycle Assessment impacts

Human health impacts and ecotoxicity are not widely used impact categories in LCAs because they have been developed with varying degrees of uncertainty and are therefore not well captured by LCAs (The Carbon Leadership Forum, 2018). Hence, academics have explored human health impacts of buildings under the so-called Indoor Environmental Quality (IEQ) category.

Indoor Environmental Quality is co-determined by several environmental factors (indoor air, thermal, lighting, and acoustics) (Yang and Mak, 2020). This is in line with Level(s) macro-objective 4 "Healthy and comfortable spaces", which defines four indicators representative of IEQ: Indoor Air Quality (indicator 4.1)[66], thermal comfort (indicator 4.2)[67], lighting and visual comfort[68] (indicator 4.3) and indicator 4.4 about acoustics and noise protection[69].

However, IEQ is not one single measurement factor, nor is there one single building design element that affects health and wellbeing. This makes it difficult to understand which environmental parameters lead to health issues and how to measure them. According to Wargocki et al., (2021), no standard set of parameters used to characterise IEQ in buildings has yet been agreed. Equally important, Toftum et al., (2021) raise the complexity of estimating the value of improved indoor environment that comes from upgrading building envelopes, ventilation, or other building features that affect the indoor environment.

To improve standardisation in this field, the framework set in the standard EN 16798 should serve as a reference to provide the necessary rules for the development of robust and common parameters. It specifies default criteria for the design of buildings and sizing of technical building systems for heating, cooling, ventilation and lighting parameters for several IEQ categories ranging from I (High) to IV (Low), based on the Predicted Percentage of Dissatisfied (PPD) and the Predicted Mean Vote (PMV). The categories are related to the level of expectations the occupants may have. A normal level would be IEQ II "Medium". A higher level may be selected for occupants with special needs (children, elderly, persons with disabilities, etc.) A lower level will not provide any health risk but may decrease comfort.

Indoor Air Quality

Because many Europeans spend more than 90% of their time inside buildings (World Health Organization, 2013), their exposure to good Indoor Air Quality becomes highly important for their health and wellbeing.

The Indoor Air Quality is determined by the concentrations of pollutants (e.g. CO_2, dust, volatile organic compounds (VOCs), etc.) and air conditions (e.g. humidity) inside the building.

Many studies consider CO_2 as a good indicator of the IAQ (Wargocki et al., 2020). It serves as a proxy for the concentration of bioeffluent in high-density occupied spaces, so high concentrations would mean insufficiently ventilated areas (Poza-Casado et al., 2021).

Although health issues attributed to CO_2 (such as respiratory problems or metabolic stress) are not common when exposed to less than 10 000 ppm, concentrations above 5 000 ppm could already be harmful over continuous 8-hour exposure and negatively affect cognitive functioning, productivity and comfort above 1 000 ppm (Coulby et al., 2020). Moreover, epidemiological studies indicate an association between low-level exposure to CO_2 beginning at 700 ppm and building-related symptoms,

[66] https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2021-02/UM3_Indicator_4.1_v1.1_37pp.pdf
[67] https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_Indicator_4.2_v1.1_24pp.pdf
[68] https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_Indicator_4.3_v1.1_15pp.pdf
[69] https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_Indicator_4.4_v1.1_17pp.pdf

such as headache, fatigue, and difficulty concentrating (Coulby et al., 2020). Thus, controlling CO_2 levels is especially relevant in offices and educational buildings in order to provide a stimulating environment to promote learning processes and productivity. Indeed, numerous studies positively relate classroom IAQ and pupils' academic performance (Toftum et al., 2021; Wargocki et al., 2020); while others show how cognitive scores of office workers and their decision-making performance decrease when CO_2 levels increase (Allen et al., 2016; Satish et al., 2012).

However, some sources warn that measurements of CO_2 trends should not be considered as a unique IAQ indicator given that they cannot be useful to predict other indoor pollutants such as Particulate Matter (PM), radon or Total Volatile Organic Compounds (TVOCs) (Poza-Casado et al., 2021; Stabile et al., 2017).

PM could result from human activity, the use of scholarly materials, and the outdoor environment. Negative health impacts associated with their exposure, particularly to PM2.5, include: cardiovascular diseases, asthma, bronchitis, premature mortality and lung cancer (Cooper et al., 2021).

Radon indoor primary sources include building materials, soil gas, and tap water and it has been demonstrated to increase lung cancer risk by 3-14%, depending on the concentration level (Tran, Park, and Lee, 2020).

TVOCs are produced by construction materials, furniture, household/office appliances (e.g., stoves and printers) cleaning products or paints and varnishes (Jiang et al., 2017). Their high concentrations are sometimes linked to the Sick building syndrome (Poza-Casado et al., 2021) and are of special importance in schools, since some of them are considered toxic and can significantly affect children (Gil-Baez et al., 2021).

In addition to the concentration of pollutants, air conditions such as humidity affect occupants' comfort. Excessively high humidity (> 90%) influence the body's energy balance, skin moisture levels and thermal sensation (Fischer and Bayer, 2003); while excessively low humidity (< 20%) can cause irritation and dryness of the eyes, nose and throat. Moreover, poor control of humidity (ranging from 65% to 99%) can create ideal conditions for mould growth (Salthammer et al., 2016), which in turn can provoke respiratory or allergenic health issues.

Research has documented that across countries, climate regions and building traditions, elementary school classrooms regularly experience inadequate Indoor Environmental Quality (Toftum et al., 2021; Wargocki et al., 2020). The most prevalent issues are poor air quality and uncomfortable thermal conditions (Toftum et al., 2021).

To avoid the issues described, harmful concentrations of pollutants should be avoided tackling the source or compensated by appropriate ventilation rates and the installation of filters. Although Heating, Ventilation and Air Conditioning (HVAC) systems have reached a high level of technological maturity, IAQ is sometimes unsatisfactory since it is affected by unexpected deficient air volume and inefficient indoor airflow patterns (Park and Chang, 2020). Moreover, airtightness of the envelope should be pursued as air infiltration could cause inhomogeneous air quality distribution through the indoor space (Poza-Casado et al., 2021). Finally, humidity should be controlled through the design of the HVAC system and the installation of dehumidifiers, in some cases.

Thermal comfort

The thermal sensation determining occupants' wellbeing is mainly related to the thermal balance of their body which may be influenced by physical activity (met) and clothing (clo), as well as the environmental parameters: air temperature and mean radiant temperature (or operative temperature, weighting both), air velocity and air humidity.

Moreover, thermal comfort is also affected by unwanted local cooling or heating of the body due to factors such as radiant temperature asymmetry (cold or warm surfaces), draught, vertical air temperature difference, and cold or warm floors.

According to Level(s) user's manual on the topic (Indicator 4.2), a large proportion of the EU's housing stock cannot provide adequate levels of thermal comfort because of a combination of a lack of insulation, poor-quality windows, cold bridging through the building fabric, high levels of air infiltration and inadequate or poorly maintained heating systems. This, in addition to discomfort, can result in seasonal illnesses and other health issues, such as perspiration, eyestrain, dizziness, accelerated respiration and heart rate in response to temperature step-changes (Xiong et al., 2015).

In the literature, the scientific community has stated high levels of dissatisfaction reported by students with the thermal environments of the classrooms (Singh et al., 2019). Research confirms the significant positive correlation found between occupants' perception of the IEQ and temperature at schools (Dorizas, Assimakopoulos, and Santamouris, 2015), meaning that the temperature was a crucial indicator of a satisfactory indoor environment for students. There is also abundant published evidence on the effects of temperature in school classrooms on children's performance. However, studies have found that only a very small proportion of variance corresponding to work performance in offices can be explained by the temperature, meaning a low relationship between both variables (Porras-Salazet al., 2021).

Users' perceptions of the same thermal environment are different. For instance, research shows that males tend to present higher percentages of acceptability of the thermal environment and that they prefer cooler temperatures compared to females (Dorizas, Assimakopoulos, and Santamouris, 2015). Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody, and the design of the building shall be such as to meet an acceptable percentage of dissatisfied occupants.

Lighting and visual comfort

Inadequate luminance and illuminance levels affect the comfort of occupants, causing visual discomfort. The impact of building interiors with inappropriate illumination results in lower productivity affecting also the behaviour of occupants (Kwong, 2020).

Scientific papers on visual comfort and users' lighting preferences indicate that people prefer much higher light levels than the minimum 500 lx generally recommended by standards and regulations. However, this statement varies across different countries and cities, which could depend on climate and cultural influences (Fakhari, Fayaz, and Asadi, 2021).

Lighting in classrooms is a major problem in educational buildings (Setiati and Budiarto, 2021). For example, a classroom has varying lighting needs because of the increasing use of electronic equipment. For instance, when natural light is used and the projector is on, students experience glare when looking at the notes on the marker board or projections on the screen in their classrooms (Setiati and Budiarto, 2021).

These considerations could also be extended to experiences in office buildings, which makes lighting an essential parameter in the EU GPP criteria.

Acoustics and protection against noise

The potential for acoustic disturbance, from both inside and outside a building, is cited as an important influence on the health, comfort and well-being of building occupants (World Green Building Council, 2014 as cited in European Commission. Joint Research Centre. Institute for Prospective Technological Studies., 2016).

Sounds from traffic, computer equipment, and HVAC systems are examples of main sources of noise inside buildings (Wang and Brill, 2021; Yang and Mak, 2020). Unfortunately, the sensors that evaluate the acoustic comfort in buildings are not always placed in the most appropriate locations (Lex et al., 2019).

Most countries in Europe have either no regulatory limits or only recommendations on acoustic criteria for offices (Rasmussen and Carrascal García, 2019). Besides background noise from ventilation and speech, the constituents of sound environments within office workplaces are diverse (Yadav et al., 2021) hence the different acoustic metrics and limit values found in European regulatory acoustic frameworks.

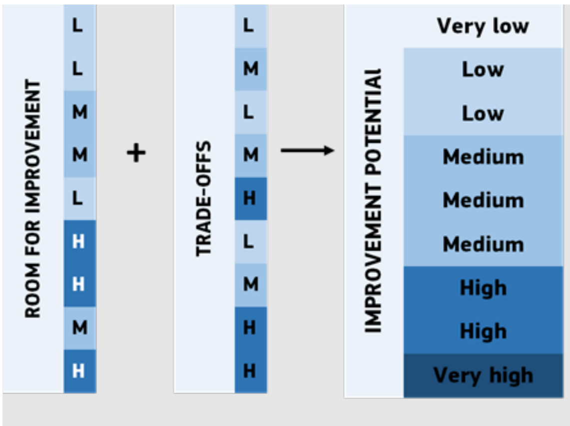
5. Task 4: Technical analysis and improvement potential

Buildings are complex systems composed of multiple and interrelated technical systems, all of which have some degree of influence on the overall life cycle impacts of the building.

This section aims to provide an overview of the building sector from a more technical perspective, explaining the options available today and their performance. The findings derived from the technical analysis will be used to estimate the improvement potential that can be achieved via technical specifications in EU GPP criteria as described in the figure below.

To show intuitively and clearly the improvement potential (Figure 26), the room for improvement of each sub-theme is evaluated, illustrating how far the average current situation is from the technological progress described in the section. Then, it is nuanced by the trade-off between barriers and enablers that boost or diminish the room for improvement to result in an approximation of the improvement potential. Thus, the hurdles or difficulties the building sector may face when applying the requirement, identified as barriers (-), need to be weighed against the enablers (+), the tools provided in the EU GPP criteria to overcome them and the particular relevance of the sub-theme for the overall sustainability of the sector.

Figure 26. Methodology for the assessment of the improvement potential of the criteria



Source: author's own elaboration.

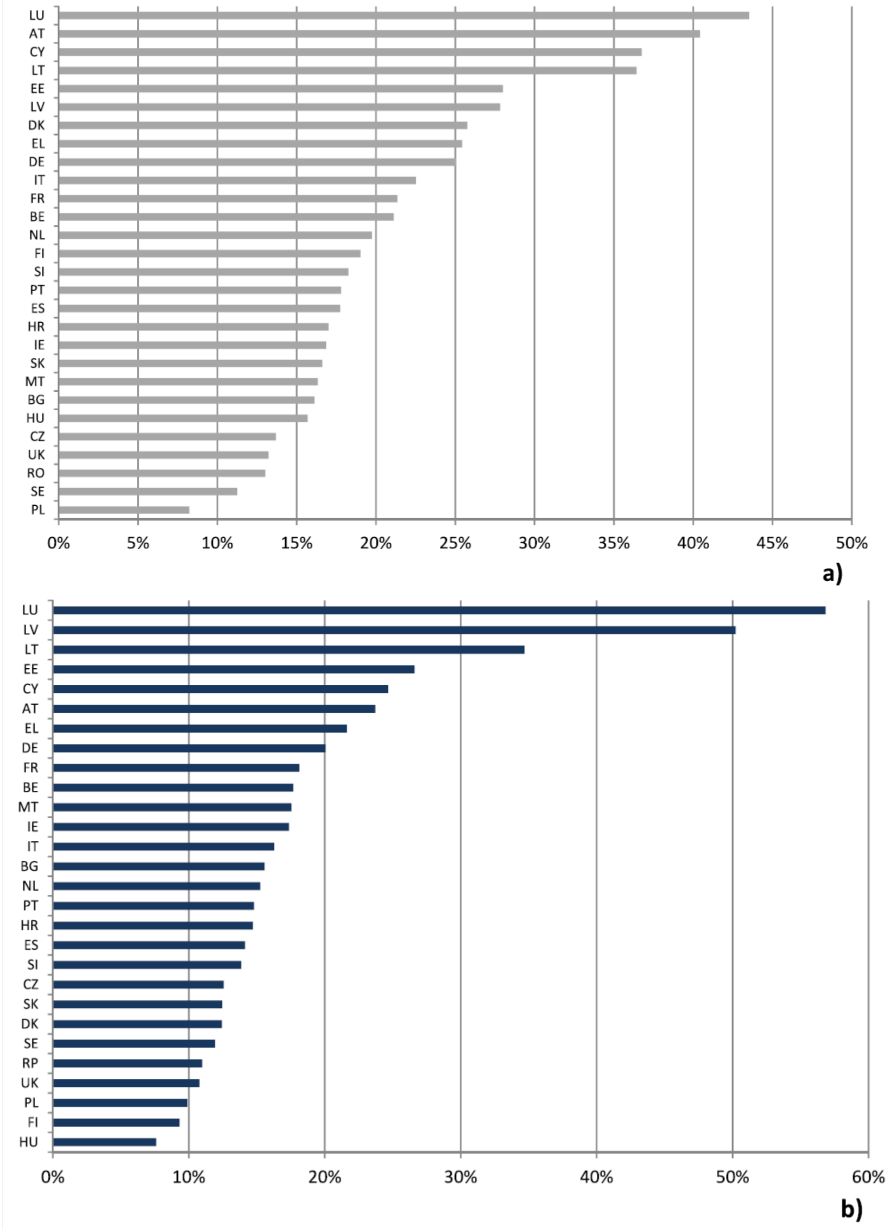
Theme 1: Energy consumption and life cycle greenhouse gas emissions

The buildings sector is responsible for 40% of the final energy consumed and 36% of the energy-related greenhouse gas emissions in the EU (European Union, 2022) in operational terms. Due to its significant contribution, it is essential to improve energy performance and move towards the decarbonisation of the sector.

In this respect, the literature shows that Nearly Zero-Energy Buildings (NZEBs) are a good benchmark, since the definition of their requirements normally refers to the cost-optimal approach (D'Agostino et al., 2021). Thus, policy actions are promoting their uptake, while defining the requirements for Zero Emission Buildings (ZEBs) to push for a higher level of ambition.

Despite the differences in the thresholds and methodologies among Member States, NZEBs represented 20% of the EU construction market in 2016, increasing at a 9% annual rate since 2012 (D'Agostino et al., 2021) . Luxembourg, Austria and Cyprus registered the largest shares (43%, 40% and 37%, respectively), while Poland, Sweden and Romania presented the lowest (8%, 11% and 13%, respectively) (Figure 27). Regarding the share of square metres in NZEB standards, they represented even more than half of the construction market in Luxembourg (57%) and Latvia (50%), while Hungary and Finland remained below 10%.

Figure 27. a) Share of NZEBs in the total construction market of Member States; b) Share of square metre of hotelNZEBs in total construction market by Member State



Source: D'Agostino et al., 2021.

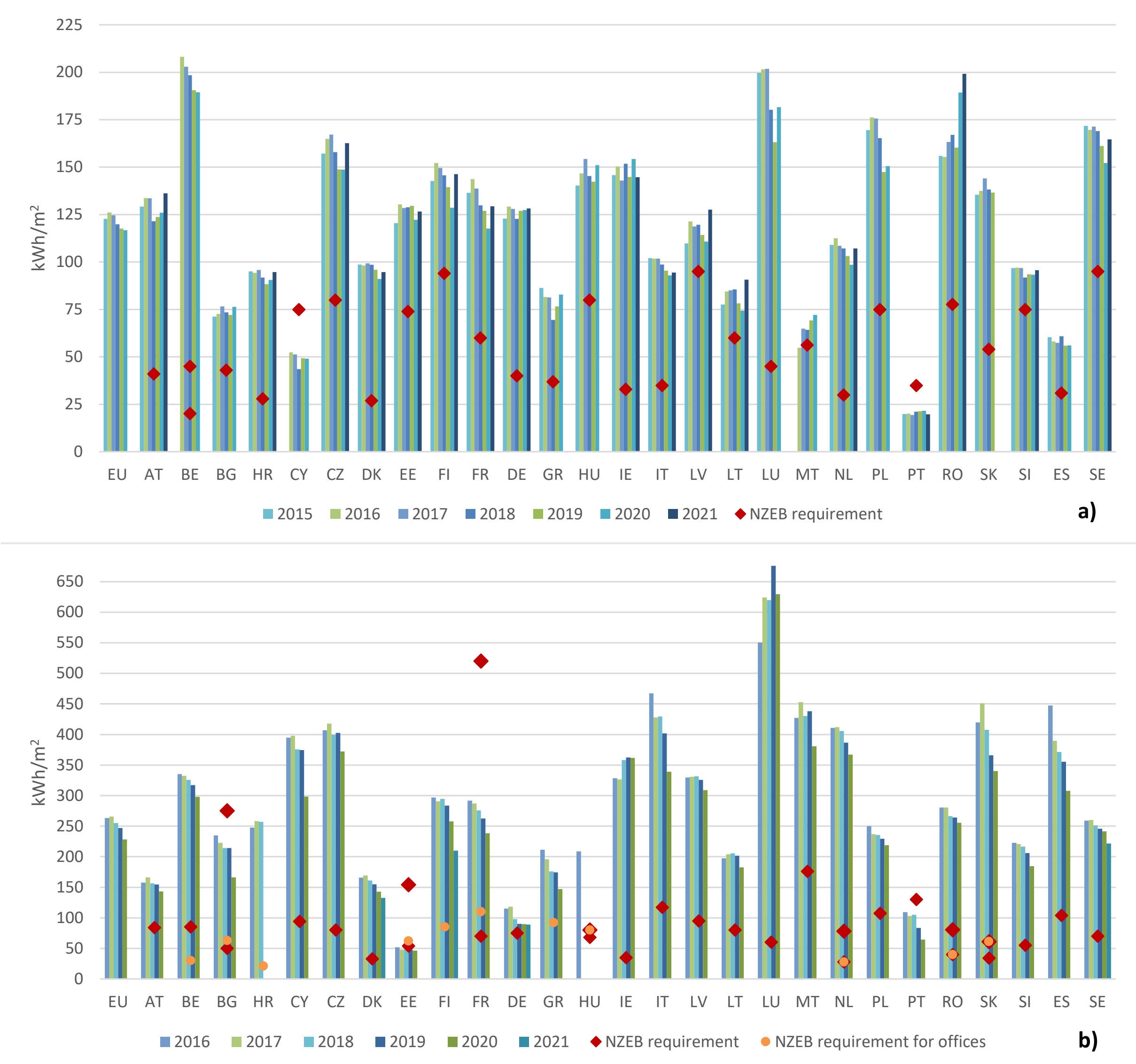
In terms of energy performance, Figure 28 shows that residential buildings in the EU achieved an improvement of 5% over the period 2015 - 2020. Despite a promising downward trend between 2016 and 2019, the numbers slightly stabilised in 2020, probably as a consequence of increases in some Member States owing to the time spent at home and new teleworking patterns due to the COVID pandemic and lockdowns. During the period under study, 15 Member States improved their energy performance, with achievements ranging from 0.4% (Croatia) to 11% (Poland). Meanwhile, 12 countries worsened their performance, with increases around 10.5%.

Figure 28 also shows how far national performances of existing residential buildings are from the thresholds in their NZEB definitions. In most cases, the latest numbers are above NZEB requirements, with the largest differences found in Ireland, Belgium and Luxembourg where the consumption is four times higher than the thresholds. Nevertheless, the gap is reduced to some 30% in Latvia, Malta and Slovenia, while the national figures even surpassed the requirements in Portugal and Cyprus.

Regarding non-residential buildings, the energy performance in the EU improved by 13% between 2016 and 2020. This was due to the achievements in most of the Member States ranging between 41% (Portugal) and 6% (Latvia and Sweden), while figures only worsened in Croatia (4%), Ireland (10%) and Luxembourg (14%).

Thresholds for non-residential NZEBs vary depending on the building functionality in some Member States. Figure 28 shows the upper and lower limits and the requirement for offices, when available. The gaps between the latest figures of national performances and the NZEB requirements in non-residential buildings are greater than in residential ones, presenting differences of up to 10 times greater in Luxembourg and Ireland. National figures are closer to the requirements in Germany (20% above the threshold), within the ranges in Bulgaria and France, and below the limits in Portugal and Estonia.

Figure 28. a) Energy performance [kWh/m²] trends (2015 - 2021) in the EU and by Member State, compared to NZEB requirements in residential buildings b) Energy performance [kWh/m²] trends (2016 - 2021) in the EU and by Member State, compared to NZEB requirements in non-residential buildings



Source: Elaborated from Odyssee (https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html), BSO (https://building-stock-observatory.energy.ec.europa.eu/database/), CA EPBD database (https://epbd-ca.eu/database-of-outputs), 2023.

There are lots of different ways to reach and exceed NZEB performance levels. In order to achieve the best results, a combination of approaches is required. First, the “energy efficiency first” principle should be supported by specifying passive building features that reduce the energy demand, and by specifying building equipment with high energy classes and encouraging the use of best available technologies. Second, the incorporation of on-site or nearby renewables to cover the reduced energy demand is an important part of the overall building energy paradigm shift. Finally, the use of building automation and control systems brings another dimension to building performance, which not only provides great benefits to the grid, but also comfort and economic benefits to building occupants.

Passive features

Energy efficiency first principle strategies should be made to save the non-necessary energy. To do so, an energy efficiency hierarchy of a solution prioritising designing and passive measures before active heating and cooling should be put in place.

For illustration, the ladder of cooling sets the following grading:

1. Build in a cool environment.
2. Keep out heat through orientation, layout of the house and solar screens.
3. Rely on passive cooling through natural ventilation, thermal mass, etc.
4. Use the active cooling through air conditioning and mechanical ventilation.

Efficient equipment

The focus on end-use technologies is of great interest, as they are responsible for most of the primary energy consumption. Product policies addressing their energy efficiency have a large potential, and already cover 80% of the final energy consumption of the buildings sector in the EU (Gonzalez-Torres et al., 2023).

Table 8 shows the distribution of the models of selected building equipment regulated by the Energy Labelling legislation. The results reveal that the models mostly concentrate on the second best energy class, confirming the room for improvement towards the top category. The biggest gap is found in the lighting sources, which are mostly grouped in the penultimate energy class since they are targeted by a newer (and thus, more updated) legislation in force since September 2021. On the other side, the seasonal space heating class at 35 °C of space and combination heaters should be revised soon as almost 60% of the models already reached the highest category.

Table 8. Model distribution of selected product groups by performance class

	Light sources	Air conditioners		Local space heaters	Water heaters	Solid fuel boilers	Space and combination heaters			Residential ventilation units
	(EU) 2019/2015	(EU) 626/2011		(EU) 2015/1186	(EU) 812/2013	(EU) 2015/1187	(EU) 811/2013			(EU) 1254/2014
		Cooling mode	Heating mode				Seasonal space heating class (55°C)	Seasonal space heating class (35°C)	Water heating class	
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
A+++		10.7	3.3	3.4	8.7	0	3.5	59.7		9.7
A++		63.0	13.6	48.6	33	8.1	57.9	25.9		29.1
A+		9.6	65.0	33.8	16.4	76	15.1	12	25.1	20.3
A	0.5	14.5	18.1	5.1	39.9	0.5	19.4	1.2	63.5	10.4
B	1.2	2.0	0.1	3	2	12.5	2.4	0.8	11.2	2.4
C	6	0.0	0.0	1.5	0	2.8	0.7	0.4	0.2	25.6
D	13	0.0	0.0	4.3	0	0.1	1	0	0	2.5
E	23.2			0.1					0	0.1
F	36.3			0.1					0	
G	19.9									

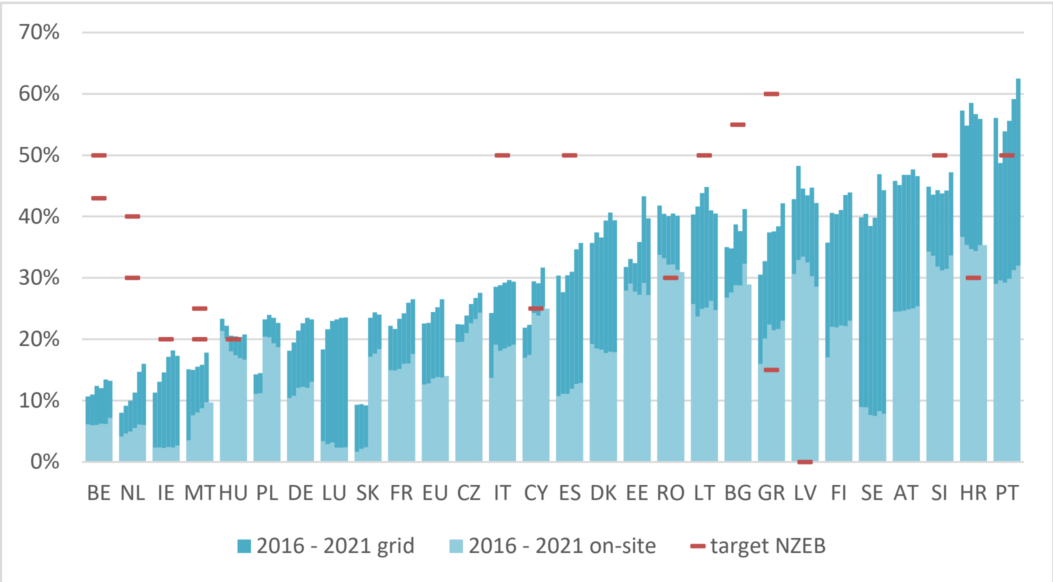
Source: European Product Registry for Energy Labelling (EPREL), available at the EPREL website.

Renewable share

As for the renewable share in buildings' energy consumption in the EU (Figure 29), it increased to 27% in 2020 due to a higher on-site generation (2%/yr) and greater presence of renewables on the grid (5%/yr) over the last 5 years. The highest shares are found in Portugal (62%) and Croatia (56%), where renewables on site already supplied a third of buildings' energy consumption. On the other side, shares were still below 20% in Malta, Ireland, the Netherlands and Belgium, despite having grown from 2016 at annual rates between 4% and 15%.

NZEB definitions include thresholds from renewable shares in 16 Member States. Most recent data showed that the thresholds are already exceeded by existing buildings in 44% of cases, also counting only on-site generation in Cyprus, Romania, Greece, Latvia and Croatia. In contrast, differences of up to 72% between the current renewable shares and the NZEB requirements are found, with Belgium and the Netherlands the ones presenting the biggest gaps.

Figure 29. Trends of renewable share (2021 - 2016) in the EU and by Member State, compared to NZEB requirements.



Note that 2021 figures of renewables share on grid are missing for MT, EU, CY, RO, BG and HR.
Sources: Elaborated from Odyssee (https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html), CA EPBD database (https://epbd-ca.eu/database-of-outputs), D'Agostino et al., (2021), IEA Energy Balances, 2023 (https://www.iea.org/data-and-statistics/data-product/world-energy-balances#overview)

Building Energy Management Systems

Building Energy Management Systems (BEMS) control energy generation and storage and allow building administrators to supervise and manage their load demand in order to increase the energy efficiency while ensuring indoor comfort for building occupants, so that the objectives of users and utility suppliers are achieved (Mariano-Hernández et al., 2021). For this purpose, BEMS are integrated in various parts of the building and use dynamic information about user activities (e.g. location), environmental conditions (e.g. climate, light) and energy supply conditions (e.g. cost, load) (Al Dakheel et al., 2020).

Statistical results as published by Lee and Cheng (2016) show that BEMS for artificial lighting systems achieved energy savings up to 40%, while improving the performance of HVAC and other equipment around 15%.

Operational vs. embodied emissions

The improvement of the energy performance of a building results in the reduction of its operational emissions, meaning those related to the direct energy use during the use phase. However, attention should also be paid to the embodied emissions for reasons that extend beyond building operation, such as the production of building materials and equipment, their transport to the construction site, the construction process and the dismantling and disposal of buildings and materials.

While the average share of embodied GHG emissions from buildings following current energy performance regulations is approximately 20–25% of life cycle GHG emissions, this figure rises to 45–50% for highly energy-efficient buildings (Röck et al., 2020), as shown in Task 3. Thus, as the building stock moves towards NZEB and the operational emissions are minimised, the environmental hotspots will shift to other stages in the life cycle of buildings, increasing the relevance of the embodied emissions (Mirabella et al., 2018).

However, commonly pursued efficiency strategies to decrease operational emissions increase the embodied emissions in the building (Ürge-Vorsatz et al., 2012). For instance, the energy demand for space heating is reduced by increasing the thickness of energy-intensive insulation materials, the energy invested in which may not be recovered within an adequate energy payback period. Thus, the trade-offs become critical and require a Life Cycle Assessment to ensure that measures are not counterproductive.

Improvement potential in Theme 1

Thus, taking into consideration all of the above, the following table illustrates how the current situation deviates from the identified technological progress and serves to estimate the improvement potential that can be achieved via the EU GPP criteria. The theme has been assessed to have a high level of potential for improvement, with the requirements on energy consumption in the use phase, renewable energy systems, commissioning of energy technical installations and the assessment of the whole life cycle being identified as key criteria.

Table 9. Improvement potential of sub-topics in Theme 1

Theme 1. Energy consumption and life cycle greenhouse gas emissions					
Criteria		Room for improvement	Trade-offs		Improvement potential
			Level	Rationale	
TS 1.1.1	Use-stage energy consumption	H	H	(+) High relevance of the subtopic for the sustainability of the whole sector.	Very high
TS 1.1.2	Passive features	H	M	(-) Need for additional awareness in the sector so that passive design solutions are prioritised.	High
TS 1.1.3	Energy-efficient HVAC, lighting, water heating and other building equipment	H	M	(-) High cost of the best performing equipment.	High

AC 1.1.3	Energy-efficient HVAC, lighting, water heating and other building equipment	H	M	(-) High cost of the best performing equipment.	High
TS 1.1.4	Installation of on-site or nearby renewable energy systems	H	H	(+) High relevance of the subtopic for the sustainability of the whole sector.	Very high
AC 1.1.4	Installation of on-site or nearby renewable energy systems	H	M	(+) High relevance of the subtopic for the sustainability of the whole sector. (-) Storage solutions still to be improved.	High
TS 1.1.5	Installation of building automation and control systems	H	M	(-) Costly installation of sensors and control strategies.	High
TS 1.2	Preliminary Whole Life Cycle Assessment	H	H	(+) High relevance of the subtopic for the sustainability of the whole sector.	Very high
AC 1.2	Preliminary Whole Life Cycle Assessment	H	M	(+) High relevance of the subtopic for the sustainability of the whole sector (-) Data unavailability and complexity in the assessment	High

Source: author's own elaboration.

Theme 2: Material circularity

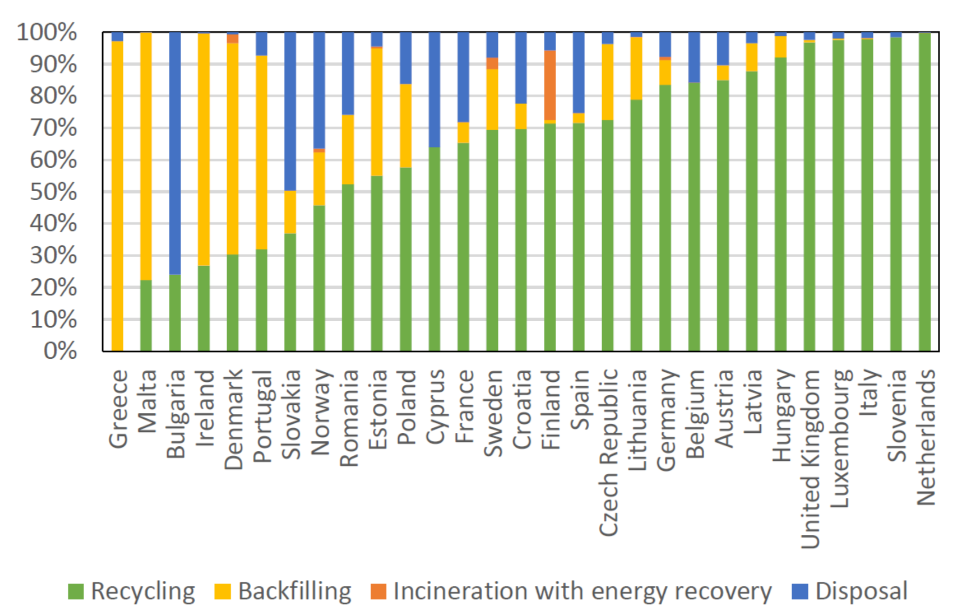
The construction and use of buildings in the EU account for about half of all our extracted materials. Construction, Demolition and Excavation Waste (CDEW) represents more than a third of all waste generated in the EU and, based on volume, is the largest waste stream in the EU. [70]

A wide variety of materials can be found in CDEW. Some of them have a high resource value, while others with lower value could still be easily reprocessed into new products or materials. Despite its potential, the level of recycling and material recovery of CDEW varies greatly across the EU, ranging from less than 10% to over 90%[71], as shown in Figure 30.

[70] Available at : https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en#:~:text=Construction%20and%20demolition%20waste%20%28CDW%29%20accounts%20for%20more,infrastructure%2C%20as%20well%20as%20road%20planning%20and%20maintenance.

[71] Available at: https://environment.ec.europa.eu/topics/waste-and-recycling/construction-and-demolition-waste_en#:~:text=Construction%20and%20demolition%20waste%20%28CDW%29%20accounts%20for%20more,infrastructure%2C%20as%20well%20as%20road%20planning%20and%20maintenance.

Figure 30. Treatment of mineral waste from construction and demolition, 2018



Source: (CEU. JRC, 2022).

According to the current policy framework in terms of material circularity for the construction sector, the key aspects focus on reducing resource use and waste generation; preparing waste for reuse, recycling and other material recovery of non-hazardous Construction and Demolition Waste; and promoting selective demolition to enable removal and safe handling of hazardous substances and facilitate reuse and high-quality recycling (European Commission, 2018).

A bill of materials plays a vital role in promoting sustainability in buildings by guiding material selection, including sustainability criteria such as using low-impact materials. A well-structured inventory minimises waste generation and supports the principles of a circular economy by including information about the recyclability and end-of-life options for each material. (European Commission, 2023). It helps integrate sustainability considerations into the construction process, resulting in greener, more resource-efficient and environmentally conscious buildings.

Deconstruction involves carefully disassembling a building to recover reusable material , paying particular attention to enabling removal and safe handling of hazardous substances to facilitate reuse and high-quality recycling of materials (European Construction Sector Observatory, 2019).

Adaptable buildings have an extended lifespan, as they can be modified or upgraded to meet current needs. This reduces the demand for new construction materials and their environmental impact (The American Institute of architects, 2020). Adaptability enhances the flexibility and resilience of buildings so that they can respond to changing climate conditions, technological advancements, and social dynamics; it also helps minimise Construction and Demolition Waste and brings economic benefits as buildings can easily be customised to suit specific needs or preferences.

Considering reparability at the design stage facilitates efficient repairs, reduces waste, and supports the long-term performance and sustainability of buildings. It promotes a proactive approach to maintenance and ensures that buildings can adapt and withstand the test of time (European Commission. Joint Research Centre, 2019).

Incorporating circular economy thinking in the design stage enables systems to be easily maintained, repaired and replaced and extends the life cycle of the buildings. All actors involved in the building sector should work together to improve waste identification, source separation and collection, waste logistics and waste processing (CEU. JRC. 2022). It should not be forgotten that proper management of CDEW increases confidence in recycled materials by boosting market demand for them (European Commission, 2022).

Operational waste management provides a comprehensive system of separate waste collection that maximises recycling opportunities and, at the same time, educates building occupants, holding them accountable for the quality of the waste fractions collected.

Improvement potential in Theme 2

Considering the above, the improvement potential of the building sector, regarding material circularity point to the design phase as a key stage in addressing deconstruction and increasing the life of the building, through design for adaptability, reparability and upgrading. Particular emphasis is placed on proper waste management to ensure a high quality of recycled materials to facilitate market uptake. Of particular relevance is the verification that what was specified during the design phase has been implemented as planned.

Table 10. Improvement potential of sub-topics in Theme 2

Theme 2. Material circularity					
Criteria		Room for improvement	Trade-offs		Improvement potential
			Level	Rationale	
TS 2.1	Bill of materials	H	H	(+) High relevance for other criteria.	Very high
TS 2.2	Design for deconstruction	H	H	(+) Template provided and easy calculation method through Level(s) (+) Data availability (-) Difficult for existing buildings	Very high
TS 2.3	Design for adaptability	H	M	(+) Template provided (-) Difficult for existing buildings	High
AC 2.4	Design for reparability	H	H	(+) Easy to fulfil	Very high
TS 2.5.1	CDEW management Plan	H	M	(+) Removal of hazardous substances (-) Selective demolition/ appropriate sorting (-) Training required (+) Template provided and easy method through Level(s) (+) Data availability	High
CPC 2.5.2	Log of waste	H	H	(+) Easy to fulfil (+) Template provided	Very high
AC 2.6	Operational waste management plan	H	M	(-) Based on consumer behaviour (+) Relevant for other criteria.	High

Source: author's own elaboration.

Theme 3: Efficient use of water resources

Scope of water systems covered

The technical performance of individual sanitary tapware and showers is addressed in the following subsections. In particular, flushing toilets, urinals, grey water recycling systems, rainwater harvesting systems and irrigation systems are considered. It does not extend to water heating systems or hot water storage tanks, which are considered as relevant to Theme 1.

Water use patterns in different building types

Investments in water efficiency are encouraged throughout the building but, in cases where limited resources are available, investments should be targeted to those sanitary fittings and appliances where most water is consumed. At a general level, the split of water consumption varies with building type, although each individual building will have its own very specific use patterns. A comparison of some of the main building types that could be under public ownership owned by public procurement are compared with each other.

Table 11. Share of water consumption in showers, toilets, washbasin and kitchen taps by building type

Building type	Toilets & urinals	Showers / baths	Washbasin taps	Kitchen taps	Other
Residential	25%	33%	7%	7%	28%
Public office	63%	0%	2%	4%	31%
Educational	28%	1%	3%	4%	64%
Health & social	45%	0%	8%	4%	43%
Recreation, culture, sport	74%	0%	4%	0%	22%

Source: Calero et al., 2014.

Toilets and urinals consistently represent important shares of water consumption for all building types, while showers and baths are only really significant in residential buildings. Office buildings, if they provide changing rooms for staff who cycle to work or fitness areas for staff to carry out lunchtime exercise activities, could have much more significant shares of water consumption due to showers than the 0% stated above. For other public buildings, targeted investments in public buildings like sports centres' changing facilities could deliver major water savings.

Rainwater systems

Implementing rainwater harvesting systems aligns with the EU Energy Performance of Buildings Directive goal of reducing resource consumption and promoting sustainable building practices. Rainwater systems allow the collection of flows of filtered rainwater and potable water back-up supply flows back into the rainwater storage system. These systems constitute a commercially available and very relevant water-saving technology especially in areas suffering draughts.

Tap and shower performance

Each tap or shower product needs to have a defined class, based on the mains water pressures it can operate satisfactorily under and the specific flow rate of the fitting under standard conditions.

Table 12. Classification of taps and shower outlets based on their flow rates according to EN 200:2008 and EN 1112:2008

Water supply system	Class	Flow rate in L/min	
		Taps	Shower outlets
Type 1	ZZ	-	1.5-7.2
	Z	≤ 9	7.2-12
	A	≤ 15.0	12-15
	S	≤ 20	15-20
	B	≤ 25	20-25
	C	≤ 30	25-30
	D	≤ 38	30-38
Type 2	X	≤ 7.5	-
	Y	≤ 15	-
	R	≤ 7.5 hot and ≤ 4.2 cold	-
	E	-	3.6-8.4
	H	-	> 8.4

Source: Cordella et al., 2014.

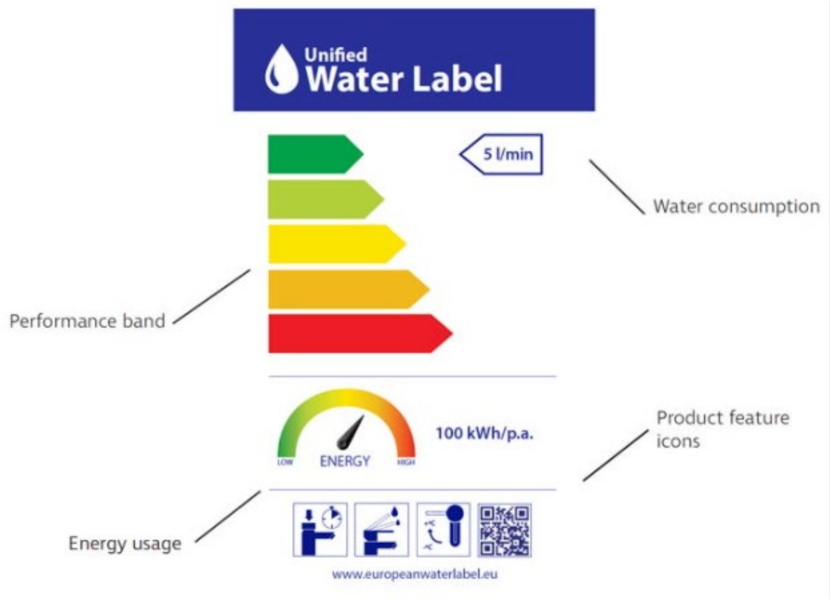
Such performance classes could potentially be used as a means to verify compliance with any EU GPP criteria since the letters for the performance class should be imprinted on the products.

Another way to potentially verify performance is to look at any voluntary water label available on the packaging of new products. A number of different national water labelling schemes have agreed to come together under the Unified Water Label, which still links to the European water label catalogue[72] and which lists thousands of different tap and shower products.

An example of what the European Water Label looks like is provided below.

[72] Available at: http://www.europeanwaterlabel.eu/findaproduct.asp?country=&category=4&rating=&manufacturer=&order=2#page=1

Figure 31. Water label for water consuming products



Source: https://www.ciphe.org.uk/newsroom/media-centre/latest-blogs/its-streamline-time-for-the-european-water-label-scheme/

A review of the products in the catalogue showed performance ranges varying as follows:

- from 3.7 to 106.4 L/min (mostly from 4.0 to 12.0 L/min) for kitchen taps;
- from 1.3 to 150.5 L/min (mostly from 4.0 to 12.0 L/min) for washbasin taps;
- from 4.0 to 120.4 L/min (mostly from 6.0 to 18.0 L/min) for shower controls;
- from 4.0 to 50.0 L/min (mostly from 6.0 to 12.0 L/min) for shower handsets.

There is clearly great potential for improvement when renovating tap and shower fittings in existing buildings. However, savings estimated due to water-efficient fittings may also be partially offset by changes to user behaviour (e.g. users may shower for longer).

Water-saving technologies and tap/shower product features

In the last 10-20 years, tap and shower technologies have shown a shift towards more water-efficient designs. The main drivers behind this shift include the following:

- The cost of supplying water is increasing and these costs are passed on to consumers in the form of higher water bills. In response to this, consumers and businesses are keen to identify and implement measures that enable them to reduce their water bills.
- Other utility costs are also increasing, for example gas and electricity. The energy consumption associated with heating water is recognised by both businesses and consumers as a potential area for cost savings.
- Consumer awareness of the environment and the impact they have on it, including their water use, is increasing. This has resulted in many consumers sourcing products that help them to achieve a more sustainable lifestyle.
- Businesses are increasingly aware of their environmental impacts and profile and the commercial benefits from improved reputation through increased Corporate Social Responsibility.
- Businesses are increasingly recognising the risk posed by water scarcity to their operations, especially those that utilise large volumes or where water is integral to or the limiting factor

in their processes. More sustainable water use will help reduce overall water consumption and minimise exposure to such risks.

- Regulations, government policies and public support to promote product innovation and development in the area of water efficiency.
- Increased provision of water efficiency labelling increases awareness and consumer/business understanding of the differences in products.

Cost ranges for different tap types, hand showers and showerheads

An analysis of costs is also important so that procurers can have an idea of how much certain specifications for taps and showers may affect the prices in different offers.

According to data provided by stakeholders during the MEErP preparatory study for taps and showers (Calero et al., 2014), the following price ranges were considered for the tap and shower products listed below.

Table 13. Indications of the prices of kitchen taps, bathroom taps, shower valves and shower outlets

Design feature	**Cost range in EUR for one unit of product (median)**			
	Kitchen taps	**Bathroom taps**	**Shower valves**	**Shower outlets**
Single control mixer	10-500 (35-100)	15–500 (35-65)	15–300 (35-65)	
Double-handle mixer • Spindle • Ceramic discs	10–500 (35-50) 10-500 (35-100)	20–150 (35-50) 15-500 (35-65)	20–150 (35-50) 15-300 (35-65)	
Pillar taps (pair)		10-150 (20-50)		
Thermostatic mixer	25-800 (60-200) Not common feature	25-800 (60-200)	25-800 (60-200)	
Self-closing tap (mechanical)	30–300 (50-120) Not common feature	30–300 (50-120)	30–700 (50-120), varying from valve to complete shower column	
Infra-red sensor tap	100–600 (185-250)	100–600 (185-250)	100–600 (185-250)	
Industrial kitchen tap	150-300 (150)			
Hand shower				5-150 (40)
Showerhead				20-200 (100)

Source: Calero et al., 2014.

Although these costs are exclusive of any installation costs, it is clear that if tenderers want, for example, a thermostatic mixer in their taps or showers, it would be best to directly specify this in the call for tender because they add a significant upfront cost to the system.

Improvement potential in Theme 3

The following table illustrates the improvement potential that can be achieved via the proposed EU GPP criteria. The theme shows a high level of potential for improvement with the requirements on per person potable water consumption, water-efficient devices and appliances, rainwater harvesting systems and especially with commissioning of technical water installations. Of particular relevance is the verification that what was specified during the design phase has been implemented as planned.

Table 14. Improvement potential of sub-topics in Theme 3

Theme 3. Efficient use of water resources						
Criteria		**Room for improvement**	**Trade-offs**		**Improvement potential**
			Level	**Rationale**	
TS 3.1	Per person potable water consumption	H	M	(-) Verification of the performance beyond the design stage. (-) Higher cost and environmental impacts in areas where desalination is necessary for water supply.	High
TS 3.2	Water-efficient devices and appliances	M	H	(+) Low cost of the best performing equipment.	High
TS 3.3	Rainwater harvesting systems	H	M	(-) High relevance of the topic especially where annual rainfall is higher as the overflow of rainwater shall be channelled to artificial rainwater runoff storage, infiltration systems or directly to the local watercourse, and this is not always possible for the building in question.	High
TS 3.4	Grey water reuse systems	H	M	(+) Reduction of the environmental impacts of delivering water to the point of demand. (-) Difficult for existing buildings.	Medium
CPC 3.5.1	Verification of compliance of the installed system	H	H	(+) Essential to confirm that the designed performance is effectively met.	Very high

Source: author's own elaboration.

Theme 4: Occupant comfort and wellbeing

Indoor Air Quality

The Indoor Air Quality can be controlled by source control, filtration, air cleaning and ventilation. The different strategies should be combined to maintain acceptable conditions.

The source control consists of the conscious selection of building materials, furniture and finishes in order to minimise or avoid harmful non-human emissions into the indoor air at the point where they can be generated. This shall serve as a primary strategy to prevent or decrease the need for subsequent removal through other strategies.

Ventilation involves the supply of air to dilute human and non-human pollutant concentrations, and correct other indoor conditions such as humidity. The required airflow rate is critical for the design, dimensioning and selection of an effective ventilation strategy, which can be done through mechanical, passive and hybrid ventilation systems.

Passive ventilation was the traditional solution for renovating the air in buildings by the natural airflows resulting from temperature and pressure difference between the indoor and outdoor environment (Gil-Baez et al., 2021). In fact, there are recent studies that confirm that Indoor Air Quality can be easily maintained in moderate climate locations (Schulze and Eicker, 2013) and controlled significantly in certain schools (Amini et al., 2021) by opening windows. However, it has been relegated to the background and even removed from the regulation in some cases, as mechanical solutions (such as fans or blowers) become cheaper and simpler to implement (Gil-Baez et al., 2021). As a result, buildings are mostly mechanically ventilated nowadays (Op't Veld, 2008), although this involves energy consumption that would otherwise have been avoided.

Despite the advantages of passive ventilation over mechanical ventilation, such as savings in energy, cost and space for HVAC systems, there are also some shortcomings such as lower control and reliability, less possibility of air treatment, acoustics issues and security concerns (Emmerich, Dols, and Axley, 2001). In particular, predicting and controlling the indoor environment in window-based ventilation systems remains an open issue. Therefore, newly developed research mostly focused on hybrid ventilation, which combines both solutions by using mechanical fans to compensate the lack of natural ventilation when outdoor conditions are not favourable or enough to provide acceptable Indoor Air Quality (Chenari, Dias Carrilho, and Gameiro da Silva, 2016). This has been demonstrated to reduce the downsides of passive ventilation, while achieving about 40% energy saving compared to conventional active systems in some climates (Ezzeldin and Rees, 2013).

In the literature, studies recommend these hybrid solutions that combine window-integrated ventilation systems with the usual HVAC central systems (Park and Chang, 2020). However, more studies on the operation method should be conducted based on factors such as season, time of day, indoor/outdoor air temperature, indoor CO_2 concentration, wind speed, humidity, rain and outdoor PM2.5 level (Wu et al., 2021) to design effective strategies that consider indoor and outdoor conditions.

In order to switch between passive and active modes, an integrated control system is required to make an informed decision as to which solution is the most suitable. This capability is usually implemented in the form of a supervisory controller, which decides and orders the operating modes (Chenari, Dias Carrilho, and Gameiro da Silva, 2016). Alternatively, the switch could be implemented based on occupancy patterns. For instance, Level(s) recommends that passive ventilation be scheduled for periods of low occupancy, and mechanical ventilation for normal and high occupancy. For meeting rooms, the mechanical system should be programmed to start one hour before the expected occupancy periods and turn off one hour after the occupancy periods, in order to provide a safety margin. Higher specific ventilation rates are recommended in bathroom and changing room areas.

In terms of matching the ventilation rate to IAQ needs, the airflow rate in mechanical systems can be set at a constant level (Constant Air Volume (CAV)) or at a variable level that adapts to the demand (Variable Air Volume (VAV)). Although VAV systems are generally more expensive, they provide more flexibility and opportunity to reach optimum ventilation rates, improving the IAQ, while greatly reducing the energy use when integrated in HVAC systems, consequently reducing building operational costs (Andersson et al., 2020).

Moreover, different control strategies can be implemented to adjust the airflow rate, as described in Level(s):

- Continual operation: very basic control, which only needs to be switched off for maintenance interventions. It is especially suitable for zones that are constantly occupied and/or where the continual introduction of pollutants, CO_2 or humidity would quickly compromise IAQ in the absence of mechanical ventilation.

- Manually managed systems: despite them requiring a person for switching on/off, these are especially useful in cases where occupation schedules are very difficult to predict.
- Timer-controlled systems: convenient option to schedule ventilation rates when occupation schedules are highly predictable.
- Presence-controlled systems: where occupant movement would trigger infrared sensors that feed back to the control circuit.
- Demand-controlled systems (based on occupant numbers): airflow rates would be automatically staged by the assumed number of occupants in the different building zones. Input data could potentially be provided by swipe card access to different zones, by detection of network activity in office devices, or by the number of registered attendees to meetings.
- Demand-controlled systems (based on an air quality indicator): airflow rates would be adjusted by real-time measurement of an indicator of Indoor Air Quality such as CO_2, humidity or VOCs. Due to the higher cost of the sensors, it is a suitable strategy where the occupancy level varies frequently such as restaurants, canteens, lecture halls, shopping malls and sports halls has has more recently begun to be incorporated into residential ventilation systems as well.

In addition, those strategies could be further adjusted, based on the results of occupants' feedback from surveys of indoor conditions, to respond to those cases in which actual occupation rates and activities deviate from design assumptions.

Finally, filtration or other air cleaning technology shall be considered to remove (i) harmful pollutants that could enter via intakes of outdoor air, (ii) indoor pollutants and (iii) concentrations of odours and gaseous contaminants. In this sense, the position of the intakes could play a decisive role in minimising the need for filtering.

Thermal comfort

The requirements regarding thermal comfort shall be used for both design of buildings (dimensioning of windows, solar shading, building mass, etc.) and HVAC systems in order to ensure a thermal environment that meets an acceptable percentage of dissatisfied occupants and avoid undesired radiant temperature asymmetry, draught, vertical air temperature difference, and cold or warm floors.

The standard EN 16798 provides guidance in this respect, and establishes categories of indoor environment based on the thermal comfort indices Predicted Mean Vote (PMV) and Percentage of people dissatisfied (PPD) (EN ISO 7730), with assumed typical levels of activity depending on the building functionality and typical values of thermal insulation for clothing differentiating among winter and summer seasons. Thus, an operative temperature interval is established that shall serve to size the cooling (using the upper values of the comfort range) and heating systems (using the lower values of the comfort range).

However, dimensioning systems so that the indoor temperature remains within the specified range even in extreme situations would result in oversized air-conditioning installations with economic and environmental implications. Thus, the standard also establishes acceptable limited time intervals during which the PMV will be allowed to stay outside the specified ranges.

As with Indoor Air Quality, designers could take advantage of natural ventilation as a passive solution to provide the desired thermal conditions. However, the rate of air exchange with the exterior must be controlled to provide the required amount of fresh air to the building while simultaneously removing excess heat in the cooling season or minimising heat losses in the heating season (Chenari, Dias Carrilho, and Gameiro da Silva, 2016).

The control strategies as described for IAQ can be implemented so that the energy consumption of the HVAC system is optimised while ensuring thermal comfort. In fact, studies indicate that about 30–39% of the energy use could be saved in office and educational environments by varying supply temperature adapted to the internal heat load (Andersson et al., 2020). In addition, feedback from occupants' surveys would provide an even better response to the demand for thermal comfort.

A checklist of relevant thermal comfort design concepts have been identified in Level(s) indicator 4.2[73] which can be taken as guidance to revise the EU GPP criteria in this field.

Lighting and visual comfort

In order to measure the appropriate illuminance in a building, different metrics can be used. Despite Daylight autonomy (DA) being the best known, which corresponds to the percentage of occupied time of a day, week, month, or year that the daylight levels are above a given target illuminance (Reinhart and Walkenhorst, 2001), the literature suggests that related metrics (Spatial daylight autonomy and Continuous daylight autonomy) are highly correlated, and there would be no major issues in using the most recently proposed Spatial daylight autonomy (sDA) as a representative value in office buildings (Lee, Boubekri, and Liang, 2019).

Moreover, the authors propose to classify the lighting metrics in two categories (1) DA, Spatial DA, Continuous DA, Daylight Factor, and MHI (Mean Hourly Illuminance), (2) Useful Daylight Illuminance (UDI) and DA, and recommend using one metric from each category to better represent the daylighting condition of an office building. Horizontal illuminance on a room area (Eh-room), on a task area (Eh-task) and Vertical eye illuminance (Ev-eye) represent other interesting possible metrics to be considered in lighting and visual comfort assessments for office buildings (Davoodi, Johansson, and Aries, 2021).

As for educational buildings, LEED v4.1, WELL Standard and BREEAM[74] use a combination of daylight availability, glare control, and daylight controls (automatic and manual) to quantify daylight. While spatial daylight autonomy and annual solar exposure (ASE) are most commonly used, some standards utilise other metrics to quantify daylight quality for schools.[75]

In any case, it should be noted that currently there is not one single metric suitable for evaluating all design quantitative and qualitative visual performance parameters (Lee, Boubekri, and Liang, 2019) hence the difficulty in choosing the most relevant metrics of interest for lighting requirements in buildings.

To improve the daylight quality, there are different technologies that can be installed. For instance, Costanzo, Evola, and Marletta, 2017 presents an interesting overview of design approaches for classrooms, such as external shading devices (i.e. louvers and movable blinds) and light shelves redirecting systems. Baloch et al., 2020 also emphasised the importance of controlling the amount of incoming daylight by paying attention to the type of lighting (artificial, natural, or a combination) or window glazing and shading. Moreover, the installation of adaptive lighting reduces electric light output in response to increasing daylight in occupied spaces.

It is of utmost importance that occupant comfort and health protection are considered at the core of lighting design in buildings. Lighting control systems are widely commercially available in Europe. However, the design of quantitative and qualitative visual performance parameters in buildings may overlook the interaction with the occupant and their well-being. There is sufficient evidence on how proper lighting favours occupant comfort, but there is room for improvement when it comes to giving more control to the user for adjusting illuminance levels.

Acoustics and protection against noise

The EU GPP criteria for office buildings in 2016 did not include acoustics and protection against noise. However, a set of acoustic design aspects have been defined in Level(s). In office buildings: (open

[73] https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_Indicator_4.2_v1.1_24pp.pdf
[74] https://www.breeam.com/BREEAMUK2014SchemeDocument/content/05_health/hea01_nc.htm
[75] https://help.covetool.com/en/articles/4966875-pursuing-alternative-daylight-standards-for-schools

plan) offices, conference rooms, high confidentiality spaces, noise-sensitive spaces (tele-conferencing, concentration…), common access areas have been considered to be of major importance. The five acoustic design aspects stated in Level(s) indicator 4.4 are: façade sound insulation, airborne sound insulation, impact sound insulation, service noise equipment and room acoustics. These design aspects are to some extent collected under the national acoustic regulations of most European countries.

In terms of metrics, Yadav et al. (2021) state that most studies on acoustics report A-weighted equivalent energy sound pressure levels over a wide range of measurement durations and locations in buildings (Yadav et al., 2021). These metrics focus mostly on noise pollution levels and noise climate. Some papers on occupant comfort also focus on reverberation times (T in seconds) and psychoacoustic metrics (e.g. loudness). In any case, the most commonly studied factors which represent the acoustic conditions in classrooms and offices seem to be the speech transmission index (STI) and the reverberation time (RT) (Mogas Recalde, Palau, and Márquez, 2021). Additionally, other studies indicated that signal to noise ratio (SNR), sound insulation, and background noise level affect acoustic comfort in educational buildings (Yang and Mak, 2020).

Improvement potential in Theme 4

The following table illustrates the improvement potential that can be achieved via the proposed EU GPP criteria. The theme shows a level of potential ranging from Medium to High, due to their relevance for the environment and the welfare of the occupants and the already advanced situation of the sector in this sense that leaves lower room for improvement.

Table 15. Improvement potential of sub-topics in Theme 4

Theme 4. Occupant comfort and well-being					
Criteria		**Room for improvement**	**Trade-offs**		**Improvement potential**
			Level	**Rationale**	
TS 4.1.1	Ventilation system performance	M	M	(+) Proved impact on comfort, health and productivity. (-) In conflict with energy conservation.	Medium
AC 4.1.1	Ventilation system performance	H	L	(-) The concentrations of such pollutants could be already within acceptable ranges due to ventilation rates defined in TS 4.1.1.	Medium
TS 4.1.2	In-situ monitoring and feedback control of ventilation performance	H	M	(-) Costly installation of sensors and control strategies.	High
TS 4.1.3	Low Volatile Organic Compound (VOC) emission construction materials	H	M	(+) Source control with positive impact on comfort and health. (-) The concentrations of such pollutants could be within acceptable ranges due to ventilation rates defined in TS 4.1.1.	High

TS 4.1.4	Access to fresh air spaces	H	H	(+) Positive impact on comfort, health and productivity.	Very high
TS 4.2.1	Thermal comfort: time out of range	M	M	(+) Positive impact on comfort. (-) In conflict with energy conservation.	Medium
TS 4.2.2	Thermal zoning and individual thermal comfort control	H	M	(-) Costly installation of sensors and control strategies.	High
TS 4.3.1	Electric lighting equipment requirements	M	M	(+) Easy to fulfil.	Medium
TS 4.3.2	Lighting levels and control	M	M	(+) Easy to fulfil. (+) Positive impact on comfort and health	Medium
TS 4.3.3	Daylight factor and glare control	M	M	(+) Easy to fulfil.	Medium
TS 4.4.1	Limits for indoor weighted average sound pressure level	M	M	(+) Positive impact on comfort and health. (+) Easy to fulfil.	Medium
TS 4.5	Physical access to the building and its services	H	M	(-) Difficult for existing buildings. (+) Positive impact on well-being.	High

Source: author's own elaboration.

Theme 5: Vulnerability and resilience to climate change

Climate is a key factor in the design, construction and operation of buildings. Climate change is already causing observable effects on the environment and impacting the buildings in which we live and work. Some of these observable effects include more extreme temperatures, higher wind speeds and heavier precipitation, all of which negatively impact buildings and their users.(European Commission. Directorate General for Climate Action., 2023)The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR6)[76] states that 'information on climate risks needs to be embedded into the architectural design, delivery and retrofitting of housing'.

Building resilience to climate change is crucial for creating sustainable and adaptable infrastructure that can effectively address the challenges posed by a changing climate. It helps protect the environment, enhances occupant well-being, and ensures the durability and economic viability of buildings.

The impacts of climate change are already being felt globally. The built environment is a sector particularly at risk (**Figure 32**) with considerable potential damages and losses to real estate. The EU

[76] *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC Sixth Assessment Report*

prioritises climate resilience and adaptation in its policy framework, encouraging Member States to incorporate resilience measures into building design, construction, and renovation to address the challenges posed by extreme weather events.

Figure 32. Impact of extreme weather events on buildings

Source: EU-Level technical guidance for adapting buildings to climate change (European Commission. Directorate General for Climate Action., 2023)[77]

Climate-resilient buildings are those that are built or renovated in a way that 'should contribute substantially to reducing or preventing the adverse impact of the current or expected future climate, or the risks of such adverse impact, whether on that building itself or on people' that inhabit it, or the nature that surrounds it and the assets that compose it (European Commission. Directorate General for Climate Action., 2023)

Climate Vulnerability Risk Assessments (CVRA) are commonly used to evaluate the potential effects of climate change on a system. They are an effective tool to identify where there is a need to adapt to future climate change.

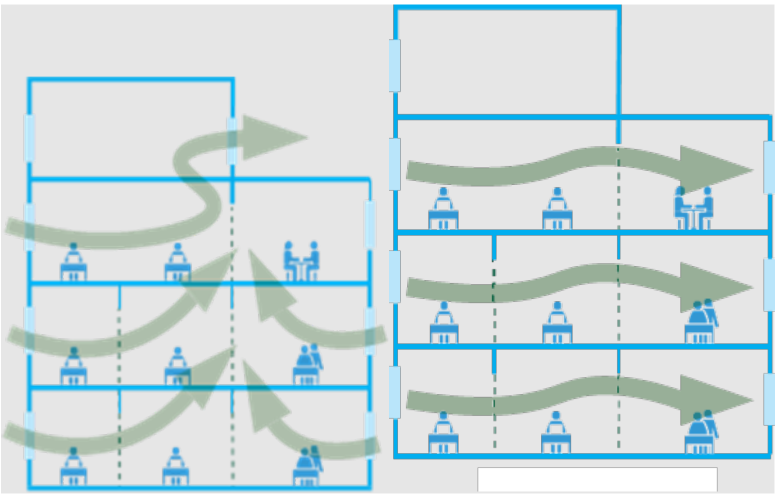
Across Europe, periods of high temperatures and heatwaves will increase in intensity and duration due to climate change. This is anticipated to be more pronounced in cities, where large volumes of heat-absorbing materials and limited green spaces generate the urban heat island effect.

Climate change is expected to exacerbate drought conditions in many regions. Droughts can lead to water scarcity, making it challenging to meet the water demands of buildings, leading to water shortages and distribution challenges, severely impacting on the availability of water for landscape irrigation, increasing energy demands for water pumping, treatment, and distribution.

Designing buildings resilient to drought and heatwaves can offer several potential environmental and social benefits such as mitigation of the urban heat island effect by the use of features such as green roofs, which reduce heat absorption and radiation; energy efficiency due to the application of features such as passive ventilation that reduce air conditioning needs and lead to lower energy consumption (**Figure 33**); improved indoor comfort incorporating measures like effective shading systems to minimise heat gain and maintain comfortable indoor temperatures; enhanced resilience and adaptation considering climate projections and integrating adaptive measures; water conservation using water-saving features such as rainwater harvesting, grey water systems, and social equity by incorporating thermal comfort considerations in low-income housing or reducing energy costs.

[77] Available at: [EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu)]

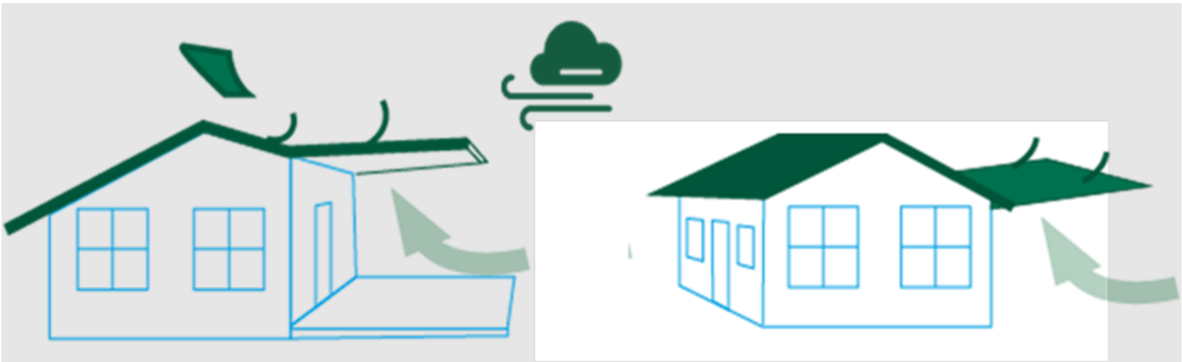
Figure 33. Passive ventilation techniques to reduce indoor temperatures



Source: EU-Level technical guidance for adapting buildings to climate change (European Commission. Directorate General for Climate Action., 2023)

Climate change is leading to more frequent and intense storms and heavy precipitation events that can result in a higher volume of rainfall over shorter durations. Intense storms can trigger soil erosion that can endanger buildings located in landslide-prone areas and can test the integrity of roofs and building envelopes (**Figure 34**).

Figure 34. Trigger points of separation between a roof and a veranda, patio or covered terrace



Source: EU-Level technical guidance for adapting buildings to climate change (European Commission. Directorate General for Climate Action., 2023)

The local or regional man-made changes that are contributing to increased flood risk are broadly related to increasing urbanisation, both in floodplains and in upstream areas that were previously greenfield sites. The result of the installation of conventional drainage systems in urbanised areas is that rainfall from a storm event landing on an impermeable urban surface is rapidly drained to the natural watercourse and this results in higher and more acute peaks in river flow rates for a given storm event. With all this water draining so quickly to the natural watercourse, the risk of fluvial flooding downstream is increased. If the drainage network becomes blocked, or was not originally designed to accept runoff from such large areas, then the risk of pluvial flooding increases in the immediate area. Elements such as sustainable drainage or water retention systems and considerations in building design regarding façade waterproofing or elevation of access points to the building are of vital importance when fighting flooding.

The EU strategy on adaptation to climate[78] which was published in 2021 actively supports the use of EU GPP criteria to deliver climate adaptation in building construction and renovation.

<u>Improvement potential in Theme 5</u>

The following table illustrates the improvement potential that can be achieved via the proposed EU GPP criteria on Vulnerability and resilience to climate change, ranging from Medium to Very high.

Table 16. Improvement potential of sub-topics in Theme 5

Theme 5. Vulnerability and resilience to climate change					
Criteria		**Room for improvement**	**Trade-offs**		**Improvement potential**
			Level	**Rationale**	
TS 5.1	Climate Vulnerability Risk Assessment (CVRA)	H	H	(+) High relevance for other criteria. (+) Guidance on key aspects provided.	Very high
TS 5.2.1	Future thermal comfort: time out of range	H	H	(+) Supported by standards. (+) Possible source of data provided.	Very high
TS 5.2.2	Passive features to minimise overheating risk	H	M	(+) Based on CVRA results. (+) Technology mature. (+) Pool of possible solutions and trade-offs. (-) Awareness in passive features.	High
TS 5.3	Design for resilience to drought	H	H	(+) Based on CVRA results. (+) Technology mature. (+) Pool of possible solutions and trade-offs.	Very high
TS 5.4	Design for resilience to storm/heavy precipitation	H	H	(+) Based on CVRA results. (+) Pool of possible solutions and trade-offs.	Very high
TS 5.5.1	Design for resilience to flooding	H	H	(+) Based on CVRA results. (+) Technology mature. (+) Pool of possible solutions and trade-offs.	Very high
AC 5.5.2	Water retention system	H	H	(+) Based on CVRA results. (+) Technology mature.	Very high
TS 5.6	Sustainable drainage	H	H	(+) Based on CVRA results. (+) Technology mature.	Very high

[78] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

TS 5.7	Resilience to mains energy and water supply failures	M	M	(-) Trade-offs when using fossil fuels. (-) Building sector skills.	Medium

Source: author's own elaboration.

Theme 6: Life Cycle Costing

Life Cycle Costing and green public procurement criteria in the EU

Life Cycle Costing is a methodology that estimates the costs of a purchase during its lifetime (OECD, 2023).

The European Commission regularly collects information about Member States' implementation of their GPP national action plans[79]. However, the monitoring carried out by the Member States on GPP on this topic is only partial. This links to the fact that the use of LCC is not well documented in general terms by the Member States, so the data about the uptake and use of LCC tools are also limited. The number of downloads of LCC tools could give an idea of the uptake of LCC in GPP. Nonetheless, LCC is not extensively used in the pre-tendering phase, which hinders the tracking of its use (OECD, 2023).

Finland and Norway are two of the countries that have assessed the uptake of LCC by means of surveys. In 2018, approximately one third of the survey respondents made use of LCC in the construction and ICT sectors in Norway. In Finland, 5% of public tenders contained LCC (OECD, 2023). However, the LCC set of techniques is very country-specific and it is not applied in a consistent way across Member States.

How to better incorporate life-cycle costing in the building contracting process

The LCC analysis is, for the most part, appropriate for the evaluation of building design options that may satisfy a required level of building performance but may have different initial investment costs, different operating and maintenance and repair costs (National Institute of Standards and Technology, 2016). Moreover, the long-term cost-effectiveness of a building project can be better assessed through LCC analyses than with other economic methods that look more into the short-term operating costs (National Institute of Standards and Technology, 2016).

Public authorities could look for potential income streams that offer a return on initial investments[80]. The following strategies could help public authorities to see public buildings as a capital cost with a long-term operational cost element:

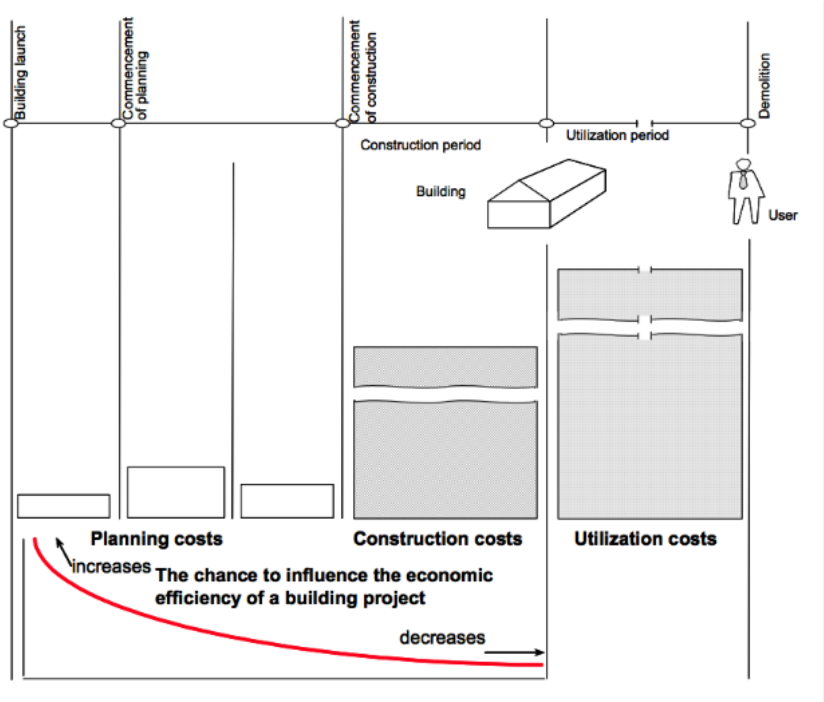
- The deliberate or unintentional oversizing of office space needs to allow for renting of space to private companies, which would also provide options for accommodating a future expansion of the public department (i.e. simply not renewing leases on the rented space to make room for extra staff).
- Another example is the generally inefficient use of large land areas associated with school buildings outside of school hours. Playgrounds could be used for farmers' markets and other events open to the public. Some schools may have great facilities for organising conferences for external parties. In densely developed areas, the land underneath the playground could be developed into underground parking.
- In terms of energy generation, the following strategies could compensate additional investment costs due to avoided energy costs and income from exported electricity: the availability of combined heat and power systems, which could be fed by biomass harvested

[79] CIRCABC. https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/3cc219c8-3c11-4aeb-8523-a85d5a6d99be?p=1&n=-1&sort=name_ASC

[80] https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf

on site or in surrounding areas, the potential to install solar panels and the potential to store electricity on site, export to the grid during peak hours or import from the grid during off-peak hours. All of these investment options and use scenarios could and should be considered before agreeing on the initial planning and building design.

Figure 35. Overview of the building design phases and linked costs



Source: European Commission - Task Group 4: Life Cycle Costs in Construction (2003). Available at: [*https://onlinebookshop.villareal.fi/docs/LifeCycleCostsinConstruction.pdf*](https://onlinebookshop.villareal.fi/docs/LifeCycleCostsinConstruction.pdf)

Challenging elements in LCC

There are a number of challenges that render mainstreaming the use of LCC among public organisations difficult:

1) Availability and reliability of data: It is not easy for public procurers to retrieve data aimed at describing the product or service life cycle (purchase price, initial costs, etc), mostly because in some cases, only the supplier has certain data (future costs of operation, maintenance, etc.)

2) Environmental considerations in the LCC calculation: LCC cannot properly translate environmental problems to price. This leads to an oversimplification of the reality.

3) Lack of knowledge among procurers

4) Environmental versus the cost-effective alternative.

LCC instruments and best practices in Member States related to construction

In Austria, Life Cycle Costing is mandatory for construction of new buildings. Furthermore, the Austrian Standards Institute developed a specific standard, which defines Life Cycle Costs in buildings, i.e. the

ÖNORM B 1801-4:2014[81]. Additionally, the Austrian working group on construction (IG Lebenszyklus Bau) has published guidelines on LCC[82].

Denmark has deployed a strategy that makes available LCC tools mandatory. The strategy also underpins financial sustainability with initiatives that prioritise the integration of LCC with Building Information Modelling (BIM)[83].

The Netherlands introduced LCC calculations based on a national environmental database of infrastructure projects[81].

In Italy, specific examples have been identified where LCC must be used as a criterion in public procurement tendering processes for new public buildings and construction projects[84].

Norway has developed a tool for buildings aimed at facilitating a simple LCC analysis of various alternative buildings. To support the uptake of LCC, authorities have been focusing on providing guidance to the public project owners and purchasers with different tools[81]. Additionally, Norway has a LCC tool for calculating the reference level for CO_2 emissions from material use in buildings.

In Germany, LCC guidelines for economically viable construction served as a model to all public new construction and renovation projects of the city of Frankfurt am Main[85].

LCC tools related to construction projects

This section gathers some of the most used computer based LCC assessment tools.

Table 17. List of the main Life Cycle Costing assessment tools

Name of the tool	Link
US National Institute of Standards and Technology (NIST) Building Life Cycle Cost Programs	https://www.energy.gov/femp/building-life-cycle-cost-programs
BDM (Bâtiments Durables Méditerranéens) Collaborative tool	http://www.enviroboite.net/outil-collaboratif-bdm-de-cout-global-et-de-benefices-durables
GSA Sustainable Facilities Tool (SFTool)	https://sftool.gov/
Dubocalc (Sustainable Construction Calculator)	https://www.dubocalc.nl/
Totem (Tool to Optimise the Total Environmental impact of Materials)	https://www.totem-building.be/

Source: author's own elaboration.

Improvement potential in Theme 6

The following table illustrates the improvement potential that can be achieved via the proposed EU GPP criteria on Life Cycle Costing. The theme shows a medium level of potential for improvement with the requirements on Life Cycle Cost assessment.

[81] ICLEI, 2018. Available at: https://iclei-europe.org/fileadmin/templates/iclei-europe/lib/resources/tools/push_resource_file.php?uid=WiTjlkpz
[82] IG Lebenszyklus Bau, 2016. Available at: https://ig-lebenszyklus.at/publikationen/
[83] Danish National Strategy for Sustainable Construction 2021. Available at: https://im.dk/Media/637602217765946554/National_Strategy_for_Sustainable_Construktion.pdf
[84] https://op.europa.eu/o/opportal-service/download-handler?identifier=28948315-41da-11ec-89db-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=
[85] City Frankfurt am Main (2020): Leitlinie zum wirtschaftlichen Bauen 2021. Available at: https://energiemanagement.stadt-frankfurt.de/Investive-Massnahmen/Leitlinien-wirtschaftliches-Bauen/Leitlinien-wirtschaftliches-Bauen.pdf

Table 18. Improvement potential for Theme 6

Theme 6. Life Cycle Costing					
Criteria		Room for improvement	Trade-offs		Improvement potential
			Level	Rationale	
TS 6.1	Preliminary Life Cycle Cost assessment	M	M	(-) High complexity when forecasting trends (e.g. labour costs, energy prices and material costs) for long building periods	Medium

Source: author's own elaboration.

Theme 7: Biodiversity

Green infrastructure: Green roofs and green façades

Green roofs and green façades are sustainable building practices that involve planting vegetation on the roof or wall of a building structure. Green roofs and green façades have been extensively analysed in the literature on a system-based level for both new buildings (Jim and Tsang, 2011; Barozzi et al., 2017) and retrofitting (Castleton et al., 2010; Barozzi et al., 2017).

Moreover, in the last couple of years the research has been focused mostly on environmental and energy-related aspects connected to green infrastructure such as the plants and growing media used in green roofs (Barozzi, Bellazzi, and Pollastro, 2016; Vera et al., 2015).

Technical aspects of green roofs

1. **Main types of green roofs**

Extensive Green Roofs: These are lightweight and low-maintenance green roofs with shallow soil layers that support drought-tolerant plants like sedums and grasses (Castleton et al., 2010).

Intensive Green Roofs: These can support a wider variety of plants due to their deeper soil layers. They can even include trees and shrubs, but they are heavier and require more maintenance (Castleton et al., 2010).

Most cities opt for extensive green roofs due to the lower maintenance, installation costs and load-bearing needs compared to the ones of intensive roofs (Jim and Tsang, 2011).

Moreover, LCA analyses conclude that extensive green roofs have less negative environmental impacts than intensive ones (Brachet, Schiopu, and Clergeau, 2019).

2. **Components**

Green roofs are layered systems constituted of a waterproofing layer (membrane) that prevents water leakage into the building structure, a root barrier that prevents plant roots from damaging the roof's waterproofing, a drainage layer that collects excess water and prevents waterlogging, a growing medium or substrate that provides a medium for plant growth, water retention, and nutrient supply (Barozzi et al., 2017; Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014; Catalano et al., 2018). An irrigation system can also be part of a green roof structure depending on the climate in which the green roof is planned on being installed (Castleton et al., 2010).

The plants chosen depend on the climate, building structure, and maintenance requirements (Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014).

3. **Benefits**

Green roofs can reduce heating and cooling costs of the building. Moreover, the shade provided by the plants of the roof can also reduce the ambient temperature (Jim and Tsang, 2011). Green roofs also absorb and slow down rainwater runoff, reducing strain on urban drainage systems. Green roofs can provide habitats for birds, insects and other wildlife (Enzi et al., 2017; Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014; Peng and Jim, 2015)**.** They enhance the visual appeal of buildings and urban landscapes too.

Plants absorb pollutants and release oxygen, improving air quality (Buffam and Mitchell, 2015). Green roofs can also provide noise insulation (Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014).

Vegetated roofs can also play a role in reducing the urban heat island effect and improving air quality (Jim and Tsang, 2011; Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014).

Technical aspects of green façades

Green walls, also called living walls or vertical gardens, are structures covered with vegetation that are attached to the exterior or interior walls of buildings. Below are some technical details about green walls:

1. **Main types of green façades**

   The classification of green façades is still a bit unclear in the different literature (Radić, Brković Dodig, and Auer, 2019). For simplicity, two main types of green façades are indicated below:

   - **Traditional green façade:** in this case, the support of the plants is the material of the façade (Pérez et al., 2011).
   - **Double-skin green façade or green curtain with perimeter flowerpots:** hanging plants are positioned around the building in the shape of a curtain (Pérez et al., 2011).

It shall be noted that the categories of green facades differ in the scientific community. Living walls were found outside the green façades group in a number of scientific papers. For instance, living walls are not part of the categories above as they are self-sufficient and do not get the water and nutrients from the ground as per Radić et al., 2019. Therefore, specific distinction is not made between green walls and green facades for the purpose of the EU GPP Buildings requirements.

2. **Components**

Similarly to green roofs, green façades count on a support structure, growing medium, if needed an irrigation system and a selection of plants (Boby, Pragyan Dash, and Shetty, 2020).

3. **Benefits of green façades**

Plants filter pollutants and enhance Indoor Air Quality (Buffam and Mitchell, 2015) while at the same time helping to moderate the indoor and outdoor temperatures (Pérez et al., 2011).

Moreover, green façades are characterised for their space efficiency as they utilise vertical space, making them suitable for urban environments with limited space. In some buildings, it is possible to have a higher number of plants installed vertically than horizontally. This is why in these cases the environmental benefits of green façades can be more prominent than the ones of green roofs (Radić, Brković Dodig, and Auer, 2019).

Additional benefits of green façades include health, better envelope protection, noise reduction, and increased property value (Knifka, Karutz, and Zozmann, 2023; Radić, Brković Dodig, and Auer, 2019; Haggag, 2010; Hop and Hiemstra, 2013)**.**

Main challenges for green roofs and green façades

Intensive green roofs can be heavy, requiring structural support adjustments. Regular maintenance is needed to prevent overgrowth, weed invasion, and plant health issues. Installation and maintenance costs can be higher than traditional roofs. Nevertheless, many studies indicate that green roofs can result in lower life-cycle costs when accounting for their benefits over their entire lifespan (Scolaro and Ghisi, 2022).

Additionally, technical issues related to membranes and heavy metals have been flagged by different studies (Chen, 2016; Karczmarczyk et al., 2020). Phosphorus and heavy metals (Pb, Zn, Cu, Hg, Cd, and Ni) are present in stormwater runoff (Wang et al., 2015; Fronczyk et al., 2016). Since green roof substrates filter rainwater, they have a negative effect on runoff quality (Catalano et al., 2018). A number of studies indicate that the organic substrate seems to be responsible for the metal discharge. However, also the mineral compounds should be carefully selected (Toland, Haggard, and Boyer, 2012). Nonetheless, it shall be noted that green roofs may be a source of pollution in the early stages of life but will constitute a sink of pollution as time passes (Akther et al., 2018; Catalano et al., 2018).

To address the issue with the heavy metals, a high-quality, durable, and root-resistant membrane suitable for green roof installations could be of help. Opting for substrates with less innate metal concentrations could contribute positively too. Nonetheless, the abundant analyses carried out in the literature focus on many factors, e.g. green roof vegetation, composition of the substrate and substrate amendments, depth of substrate, roof age, maintenance and climatic conditions and consensus among researchers seems difficult to find (Alsup et al., 2011; Buffam and Mitchell, 2015; Catalano et al., 2018). In any case, as Alsup et al. (2011) indicate, the providers are not able to control all the factors associated with green roofs and water quality issues.

Implementing green systems can bring about several environmental and economic burdens considering materials extraction, production, and transportation of raw materials, construction, operation, maintenance and end-of-life (Law, Diemont, and Toland, 2017). Consequently, a whole lifecycle perspective is essential to assess whether the benefits outweigh the impacts and justify the installation. The literature points to the construction and disposal stages as those having the highest environmental impacts (Shafique et al., 2020). This results in studies indicating almost the same (Gargari et al., 2016) and even worst environmental performance of green systems over traditional ones (Angelakoglou, Dimitriou, and Gaidajis, 2013).

However, many LCA studies have concluded green roofs are more suitable sustainable options. (Saiz et al., 2006) reported reductions between 1 and 5.3% in different impact categories, with most of the benefits occurring in the use stage due to a lower energy consumption. Similarly, (El Bachawati et al., 2016) showed that extensive green roofs performed better than traditional ones for all impact categories on human health, ecosystems quality, climate change and resources. (Cerón-Palma et al., 2013) reported reductions of up to 24.5% GHG emissions so contributing to lower global warming potential. Moreover, although studies of these rooftop technologies are often located in hot climates, (Cubi et al., 2016) showed that green roofs result in beneficial environmental impacts also in Canada, being this also applicable to cold climates in general.

Despite the fact that the publications suggesting positive results outnumber the negative ones, their implementation requires comprehensive assessment to provide a sustainable design. The net environmental benefit is always dependent on the use of natural resources and choices as regards the use of materials (Bozorg Chenani, Lehvävirta, and Häkkinen, 2015). Consequently, safer and more sustainable materials are required to be used in their construction, suggesting the use of recycled materials as an optimal choice to reduce negative environmental impacts during the materials extraction as well as the disposal phase (Shafique et al., 2020).

Technical issues on artificial light at night and biodiversity

Artificial light at night (ALAN) can have significant impacts on biodiversity, disrupting natural ecosystems and behaviour patterns of various organisms.

Several technical issues related to ALAN and its effects on biodiversity should be considered. Excessive light intensity can disorient nocturnal animals and disturb their feeding and breeding behaviours but also certain light wavelengths, particularly blue and white light, can have more disruptive effects on wildlife than others. Birds, insects, and other species may be particularly sensitive to specific wavelengths of light. **Figure 36** offers a view of the different ranges of light exposure that may affect animals, in particular the illuminance levels from which ALAN is intensified.

Skyglow is the brightening of the night sky over populated areas due to the scattering of artificial light by particles and gases in the atmosphere. It can affect astronomical observations and disrupt natural ecosystems.

Excessive or misdirected artificial light can lead to light pollution, which interferes with natural darkness and can impact wildlife behaviour, migration, and predator-prey interactions.

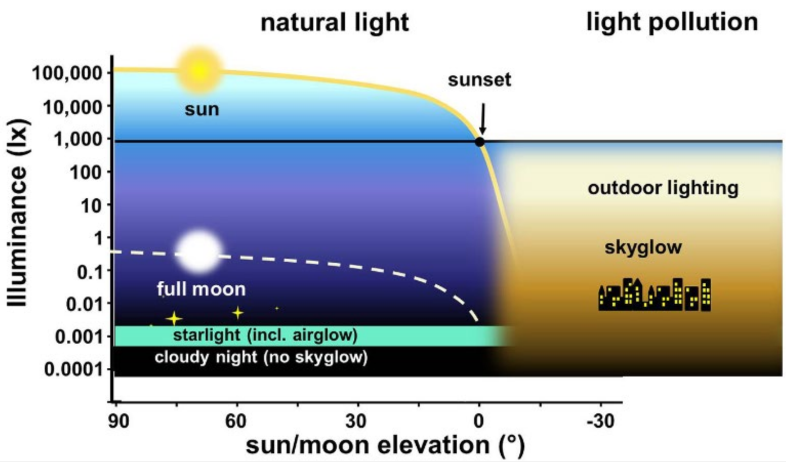
Strategies to mitigate Artificial Light at Night effects are connected to the type of light orientation, proper shielding, intensity scaled to intended use, and spectral tuning (Hölker et al., 2010a; Gaston et al., 2012; Schroer and Hölker, 2017 as cited in Hölker,2021[86]). However, there is not enough evidence on which are the best approaches that may reduce the ALAN effects on biodiversity (Hölker et al., 2021).

Some of the most mentioned mitigation strategies considered in the construction sector are the following:

- **Proper Lighting Design:** Employing shielded, well-directed lighting can minimize light spill and glare.
- **Colour Temperature:** Opt for warmer colour temperatures (less blue and white) to reduce the disruptive effects of light on wildlife.
- **Light limitations and dimming:** Implementing certain restrictions for outdoor lighting and using dimming technology during non-peak hours.
- **Sensitive Areas:** Identify and protect areas with high biodiversity value by limiting or eliminating ALAN.

Addressing these technical issues requires a multidisciplinary approach involving ecologists, urban planners, lighting designers, and policymakers. By adopting responsible lighting practices and considering the needs of nocturnal organisms, it is possible to mitigate the negative effects of artificial light at night on biodiversity and promote the coexistence of human activities and natural ecosystems.

Figure 36. Ranges of light exposure that animals experience and respond to



Source: Hölker et al., 2021.

The consideration of artificial light at night (ALAN) effects on biodiversity in construction projects can vary significantly depending on factors such as project scale, location, regulatory requirements, awareness of the issue, and the specific goals of the project.

Moreover, an operational four-step process to characterise the dark infrastructure of the building site would be beneficial to avoid the effects of ALAN and would require the following activities (Sordello, et al., 2022):

1. Map the ALAN pressure in the building site.
2. Determine the lowest level of ALAN for which effects are observed on species or ecosystems.
3. Preserving and restoring the dark infrastructure.
4. Assessing the effectiveness of the dark infrastructure.

Stakeholders in Europe have already carried out different dark infrastructure projects to preserve and restore darkness, in both urban (from a single municipality or even a neighbourhood) and natural contexts. The potential problems that may arise could be the lack of lighting and biodiversity data availability to determine species sensitivity thresholds, modelling methods, governance and status of protection.

<u>Chain of custody for wood products in buildings</u>

The chain of custody for wood products in buildings refers to the documented tracking and verification process that ensures the origin and legality of wood used in construction or products. This process is crucial for promoting sustainable and responsible sourcing practices, preventing illegal logging, and supporting ethical and environmentally friendly building practices.

By following the chain of custody for wood products, building professionals can contribute to sustainable construction practices, support responsible forestry management, and mitigate the environmental impact associated with deforestation and illegal logging. It is important to note that practices and regulations might vary by region, so staying informed about local requirements and guidelines is essential.

Achieving a high certification rate for wood products in buildings is certainly feasible, but it would depend on several factors, including the availability of certified wood sources, the commitment of the construction industry, local regulations, market demand, and the support of stakeholders. Below are some considerations:

1. Availability of Certified Wood

- The feasibility of achieving a high certification rate depends on the availability of certified wood products in the market. If certified wood is readily available and affordable, achieving a 70% certification rate (as required in the EU GPP criteria) becomes more feasible.

2. Industry Commitment

- The commitment of architects, builders, contractors, and other stakeholders to using certified wood is crucial. Raising awareness about the benefits of certified wood and promoting responsible sourcing can encourage industry-wide adoption.

3. Market Demand

- If there is strong demand from consumers, developers, and project owners for sustainable and certified building materials, it can drive the use of certified wood products.

4. Financial Considerations

- The cost of certified wood products compared to non-certified options could influence the adoption rate. If the price differential is manageable, it may incentivise more projects to use certified wood.

5. Government Regulations and Incentives

- Government regulations and incentives can play a significant role in promoting the use of certified wood. If there are policies that require or encourage the use of sustainable materials, it could drive up the certification rate.

6. Education and Awareness

- Educating stakeholders about the importance of certified wood, its benefits for the environment, and its role in sustainable construction can increase adoption rates.

7. Collaboration with Suppliers

- Collaboration with certified wood suppliers is crucial. Suppliers can help ensure a consistent supply of certified products and provide guidance on their proper use.

8. Certification Standards

- The availability of recognised and respected certification standards like FSC or PEFC can facilitate the certification process and give confidence to buyers.

9. Local Factors

- Factors such as regional preferences, local regulations, and cultural norms can influence the feasibility of achieving a high certification rate.

Improvement potential in Theme 7

The following table illustrates the improvement potential that can be achieved via the proposed EU GPP criteria on Biodiversity. The theme shows a very high level of potential for improvement with the requirements on landscaping and habitat creation and chain of custody for wood products in buildings. The improvement potential is high for the requirements on green roofs, green façades and ALAN.

Table 19. Improvement potential for Theme 7

Theme 7. Biodiversity					
Criteria		**Room for improvement**	**Trade-offs**		**Improvement potential**
			Level	**Rationale**	
TS 7.1.1	Landscaping and habitat creation	H	H	(+) High relevance for and interlinked with other criteria.	Very high
TS 7.1.2	Green roofs	H	M	(-) The degree of enhancement of the on-site green infrastructure is very dependent on building site context. (-) Difficult for existing buildings.	Medium
TS 7.1.3	Green façades	H	M	(+) Substantial contribution by achieving a gain in biodiversity through improving the green infrastructure. (-) Difficult for existing buildings.	Medium
TS 7.2.	Artificial light at night (ALAN)	H	M	(-) High impact on fauna but lack of legislative framework at EU level hence different approaches to ALAN.	High

TS 7.3	Chain of custody for wood products in buildings	H	H	(+) High relevance. (+) Easy to fulfil.	Very high

Source: author's own elaboration.

6. Conclusions

The building sector, due to its high environmental impact, is key to the transition towards a circular and sustainable economy, as well as the decarbonisation of Europe. The revision of the EU GPP criteria for buildings represents an opportunity to target the issues and construct buildings with less impact over their life cycle.

The background report identifies the need for the selection criteria to be used as a vehicle to raise awareness in the sector and promote greater skills in the field of sustainability among the actors involved. Likewise, the comprehensive level of ambition as well as the award criteria are crucial to reward those projects conceived with a more demanding circular approach.

Special attention has been paid to flag the design phase, which has a crucial role in important aspects such as energy efficiency, preventing energy consumption through passive strategies; repair, using easy-to-dismount elements; deconstruction, considering selective demolition; high-quality recycling, avoiding materials containing hazardous substances and resilience, anticipating solutions to extreme weather events.

The use of criteria by exploiting their synergies can increase their positive impact, so that when we use green systems we are not only benefiting biodiversity but we are also having an impact on the well-being and thermal comfort of the occupants, allowing us to capture humidity and even adapting the building to climatic risks such as drought. In addition to this, we must consider the different trade-offs to avoid, for example the rise in embodied carbon due to an increase in the use of materials.

The criteria should be conceived as a broad and detailed set of measures from which to choose the most appropriate ones to adapt, both to the project to be developed by the contracting authority and to the local reality in which it is carried out. To be a success, EU GPP needs clear, up-to-date and verifiable environmental criteria.

Moreover, to provide a proposal of solutions that individually or jointly ensure the sustainability of the building, whether new construction for refurbishment, prescription should be avoided as far as possible, opting for flexible solutions that can adapt to the different social, cultural, economic and climatic realities coexisting in the EU.

7. References

Akther, M., J. He, A. Chu, C. Valeo, U.T. Khan, and B. van Duin, 'Response of Green Roof Performance to Multiple Hydrologic and Design Variables: A Laboratory Investigation', Water Science and Technology, Vol. 77, No. 12, August 1, 2018, pp. 2834–2840.

Al Dakheel, J., C. Del Pero, N. Aste, and F. Leonforte, 'Smart Buildings Features and Key Performance Indicators: A Review', Sustainable Cities and Society, Vol. 61, October 2020, p. 102328.

Allen, J.G., P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, and J.D. Spengler, 'Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments', Environmental Health Perspectives, Vol. 124, No. 6, June 2016, pp. 805–812.

Alsup, S.E., S.D. Ebbs, L.L. Battaglia, and W.A. Retzlaff, 'Heavy Metals in Leachate from Simulated Green Roof Systems', Ecological Engineering, Vol. 37, No. 11, November 2011, pp. 1709–1717.

Amarasinghe, S.D.I.A., and C. Hadiwattege, 'Construction Industries' LCA Adaptability: A Desk Study Based SWOT Analysis', Proceedings of the International Conference on Industrial Engineering and Operations Management, Dubai, 2020.

Amini, R., A. Ghaffarianhoseini, A. Ghaffarianhoseini, and U. Berardi, 'Numerical Investigation of Indoor Thermal Comfort and Air Quality for a Multi-Purpose Hall with Various Shading and Glazing Ratios', Thermal Science and Engineering Progress, Vol. 22, May 2021, p. 100812.

Andersson, H., A. Kabanshi, M. Cehlin, and B. Moshfegh, 'On the Ventilation Performance of Low Momentum Confluent Jets Supply Device in a Classroom', Energies, Vol. 13, No. 20, October 16, 2020, p. 5415.

Angelakoglou, K., M. Dimitriou, and G. Gaidajis, 'Comparative Evaluation of Flat Roof Thermal Systems in Greece', International Journal of Sustainable Building Technology and Urban Development, Vol. 4, No. 3, September 2013, pp. 243–257.

Baloch, R., C. Nichole Maesano, J. Christoffersen, C. Mandin, E. Csobod, E. de Oliveira Fernandes, I. Annesi-Maesano, and on behalf of the SINPHONIE Consortium, 'Daylight and School Performance in European Schoolchildren', International Journal of Environmental Research and Public Health, Vol. 18, No. 1, December 31, 2020, p. 258.

Barozzi, B., A. Bellazzi, C. Maffè, and M. Pollastro, 'Measurement of Thermal Properties of Growing Media for Green Roofs: Assessment of a Laboratory Procedure and Experimental Results', Buildings, Vol. 7, No. 4, October 26, 2017, p. 99.

Barozzi, B., A. Bellazzi, and M. Pollastro, 'The Energy Impact in Buildings of Vegetative Solutions for Extensive Green Roofs in Temperate Climates', Buildings, Vol. 6, No. 3, August 26, 2016, p. 33.

Belyaev, I., A. Dean, H. Eger, G. Hubmann, R. Jandrisovits, M. Kern, M. Kundi, et al., 'EUROPAEM EMF Guideline 2016 for the Prevention, Diagnosis and Treatment of EMF-Related Health Problems and Illnesses', Reviews on Environmental Health, Vol. 31, No. 3, January 1, 2016.

Berardi, U., A. GhaffarianHoseini, and A. GhaffarianHoseini, 'State-of-the-Art Analysis of the Environmental Benefits of Green Roofs', Applied Energy, Vol. 115, February 2014, pp. 411–428.

BioInitiative, A Rationale for Biologically-Based Exposure Standards for Low-Intensity Electromagnetic Radiation, 2012.

Björklund, A.E., 'Survey of Approaches to Improve Reliability in LCA', The International Journal of Life Cycle Assessment, Vol. 7, No. 2, March 2002, p. 64.

Bozorg Chenani, S., S. Lehvävirta, and T. Häkkinen, 'Life Cycle Assessment of Layers of Green Roofs', Journal of Cleaner Production, Vol. 90, March 2015, pp. 153–162.

Brachet, A., N. Schiopu, and P. Clergeau, 'Biodiversity Impact Assessment of Building's Roofs Based on Life Cycle Assessment Methods', Building and Environment, Vol. 158, July 2019, pp. 133–144.

Buffam, I., and M.E. Mitchell, 'Nutrient Cycling in Green Roof Ecosystems', in R.K. Sutton (ed.), Green Roof Ecosystems, Vol. 223, Ecological Studies, Springer International Publishing, Cham, 2015, pp. 107–137.

Calero, M., M. Cordella, E. Garbarino, F. Mathieux, and O. Wolf, MEErP Preparatory Study on Taps and Showers: Final Report, Publications Office of the European Union, Luxembourg, 2014.

Castleton, H.F., V. Stovin, S.B.M. Beck, and J.B. Davison, 'Green Roofs; Building Energy Savings and the Potential for Retrofit', Energy and Buildings, Vol. 42, No. 10, October 2010, pp. 1582–1591.

Catalano, C., V.A. Laudicina, L. Badalucco, and R. Guarino, 'Some European Green Roof Norms and Guidelines through the Lens of Biodiversity: Do Ecoregions and Plant Traits Also Matter?', Ecological Engineering, Vol. 115, May 2018, pp. 15–26.

Cerón-Palma, I., E. Sanyé-Mengual, J. Oliver-Solà, J.-I. Montero, C. Ponce-Caballero, and J. Rieradevall, 'Towards a Green Sustainable Strategy for Social Neighbourhoods in Latin America: Case from Social Housing in Merida, Yucatan, Mexico', Habitat International, Vol. 38, April 2013, pp. 47–56.

CEU. JRC., Background Data Collection and Life Cycle Assessment for Construction and Demolition Waste (CDW) Management., Publications Office, LU, 2022.

Chastas, P., T. Theodosiou, K.J. Kontoleon, and D. Bikas, 'Normalising and Assessing Carbon Emissions in the Building Sector: A Review on the Embodied CO 2 Emissions of Residential Buildings', Building and Environment, Vol. 130, February 2018, pp. 212–226.

Chen, C.-F., 'EFFECTS OF SUBSTRATES AND PLANT SPECIES ON WATER QUALITY OF EXTENSIVE GREEN ROOFS', Applied Ecology and Environmental Research, Vol. 14, No. 2, 2016, pp. 77–91.

Chenari, B., J. Dias Carrilho, and M. Gameiro da Silva, 'Towards Sustainable, Energy-Efficient and Healthy Ventilation Strategies in Buildings: A Review', Renewable and Sustainable Energy Reviews, Vol. 59, June 2016, pp. 1426–1447.

Concrete Centre, Life Cycle Carbon Analysis of a Concrete Apartment Block., 2022.

Cooper, E., Y. Wang, S. Stamp, E. Burman, and D. Mumovic, 'Use of Portable Air Purifiers in Homes: Operating Behaviour, Effect on Indoor PM2.5 and Perceived Indoor Air Quality', Building and Environment, Vol. 191, March 2021, p. 107621.

Costanzo, V., G. Evola, and L. Marletta, 'A Review of Daylighting Strategies in Schools: State of the Art and Expected Future Trends', Buildings, Vol. 7, No. 4, May 13, 2017, p. 41.

Coulby, G., A. Clear, O. Jones, and A. Godfrey, 'A Scoping Review of Technological Approaches to Environmental Monitoring', International Journal of Environmental Research and Public Health, Vol. 17, No. 11, June 4, 2020, p. 3995.

Cubi, E., N.F. Zibin, S.J. Thompson, and J. Bergerson, 'Sustainability of Rooftop Technologies in Cold Climates: Comparative Life Cycle Assessment of White Roofs, Green Roofs, and Photovoltaic Panels', Journal of Industrial Ecology, Vol. 20, No. 2, April 2016, pp. 249–262.

D'Agostino, D., S.T. Tzeiranaki, P. Zangheri, and P. Bertoldi, 'Assessing Nearly Zero Energy Buildings (NZEBs) Development in Europe', Energy Strategy Reviews, Vol. 36, July 2021, p. 100680.

Davoodi, A., P. Johansson, and M. Aries, 'The Implementation of Visual Comfort Evaluation in the Evidence-Based Design Process Using Lighting Simulation', Applied Sciences, Vol. 11, No. 11, May 28, 2021, p. 4982.

Del Rosario, P., E. Palumbo, and M. Traverso, 'Environmental Product Declarations as Data Source for the Environmental Assessment of Buildings in the Context of Level(s) and DGNB: How Feasible Is Their Adoption?', Sustainability, Vol. 13, No. 11, May 29, 2021, p. 6143.

Dorizas, P.V., M.-N. Assimakopoulos, and M. Santamouris, ‘A Holistic Approach for the Assessment of the Indoor Environmental Quality, Student Productivity, and Energy Consumption in Primary Schools’, Environmental Monitoring and Assessment, Vol. 187, No. 5, May 2015, p. 259.

El Bachawati, M., R. Manneh, R. Belarbi, T. Dandres, C. Nassab, and H. El Zakhem, ‘Cradle-to-Gate Life Cycle Assessment of Traditional Gravel Ballasted, White Reflective, and Vegetative Roofs: A Lebanese Case Study’, Journal of Cleaner Production, Vol. 137, November 2016, pp. 833–842.

Emmerich, S, Dols, W, and Axley, J., Natural Ventilation Review and Plan for Design and Analysis Tools., US Department of Commerce, Technology Administration, National Institute of Standards and Technology, Springfield, VA, 2001.

Enzi, V., B. Cameron, P. Dezsényi, D. Gedge, G. Mann, and U. Pitha, ‘Nature-Based Solutions and Buildings – The Power of Surfaces to Help Cities Adapt to Climate Change and to Deliver Biodiversity’, in N. Kabisch, H. Korn, J. Stadler, and A. Bonn (eds.), Nature-Based Solutions to Climate Change Adaptation in Urban Areas, Theory and Practice of Urban Sustainability Transitions, Springer International Publishing, Cham, 2017, pp. 159–183.

European Commission, Guidelines for the Waste Audits before Demolition and Renovation Works of Building, 2018.

———, Study on Circular Economy Principles for Buildings’ Design: Final Report. Available, 2022.

———, Third Meeting of the High Level Construction Forum: Launch of the Transition Pathway for Construction, 2023.

European Commission. Directorate General for Climate Action., EU-Level Technical Guidance on Adapting Buildings to Climate Change., Publications Office, LU, 2023.

———, EU-Level Technical Guidance on Adapting Buildings to Climate Change: Best Practice Guidance., Publications Office, LU, 2023.

European Commission. Joint Research Centre., Analysis and Development of a Scoring System for Repair and Upgrade of Products: Final Report., Publications Office, LU, 2019.

European Commission. Joint Research Centre. Institute for Prospective Technological Studies., Green Public Procurement Criteria for Office Building Design, Construction and Management: Technical Background Report and Final Criteria., Publications Office, LU, 2016.

European Construction Sector Observatory, EU Construction Sector: In Transition towards a Circular Economy, 2019.

European Union, Infographic - Fit for 55: Making Buildings in the EU Greener, 2022.

Ezzeldin, S., and S.J. Rees, ‘The Potential for Office Buildings with Mixed-Mode Ventilation and Low Energy Cooling Systems in Arid Climates’, Energy and Buildings, Vol. 65, October 2013, pp. 368–381.

Fakhari, M., R. Fayaz, and S. Asadi, ‘Lighting Preferences in Office Spaces Concerning the Indoor Thermal Environment’, Frontiers of Architectural Research, Vol. 10, No. 3, September 2021, pp. 639–651.

Fischer, J.C., and C.W. Bayer, Report Card on Humidity Control: Failing Grade for Many Schools., ASHRAE J., 2003.

Fronczyk, J., M. Radziemska, P. Dynowski, Z. Mazur, and M. Bazydło, ‘Quality of Water in the Road Drainage Systems in the Warsaw Agglomeration, Poland’, Water, Vol. 8, No. 10, September 29, 2016, p. 429.

Gargari, C., C. Bibbiani, F. Fantozzi, and C.A. Campiotti, ‘Environmental Impact of Green Roofing: The Contribute of a Green Roof to the Sustainable Use of Natural Resources in a Life Cycle Approach’, Agriculture and Agricultural Science Procedia, Vol. 8, 2016, pp. 646–656.

Gil-Baez, M., J. Lizana, J.A. Becerra Villanueva, M. Molina-Huelva, A. Serrano-Jimenez, and R. Chacartegui, 'Natural Ventilation in Classrooms for Healthy Schools in the COVID Era in Mediterranean Climate', Building and Environment, Vol. 206, December 2021, p. 108345.

Gomes Silva, S., and M.L. Pulgrossi, 'When Part Is Too Little: Cutoff Rules' Influence on LCA Application to Whole- Building Studies', 2020.

Gonzalez-Torres, M., P. Bertoldi, L. Castellazzi, and L. Perez-Lombard, 'Review of EU Product Energy Efficiency Policies: What Have We Achieved in 40 Years?', Journal of Cleaner Production, Vol. 421, October 2023, p. 138442.

Haggag, M.A., 'The Use of Green Walls in Sustainable Urban Context: With Reference to Dubai, UAE', La Coruna, Spain, 2010, pp. 261–270.

Hölker, F., J. Bolliger, T.W. Davies, S. Giavi, A. Jechow, G. Kalinkat, T. Longcore, et al., '11 Pressing Research Questions on How Light Pollution Affects Biodiversity', Frontiers in Ecology and Evolution, Vol. 9, December 8, 2021, p. 767177.

Hop, M.E.C.M., and J.A. Hiemstra, 'CONTRIBUTION OF GREEN ROOFS AND GREEN WALLS TO ECOSYSTEM SERVICES OF URBAN GREEN', Acta Horticulturae, No. 990, May 2013, pp. 475–480.

Housing Europe, The State of Housing in Europe, 2021.

Housing Europe, The State of Housing in Europe, 2023.

Jiang, C., D. Li, P. Zhang, J. Li, J. Wang, and J. Yu, 'Formaldehyde and Volatile Organic Compound (VOC) Emissions from Particleboard: Identification of Odorous Compounds and Effects of Heat Treatment', Building and Environment, Vol. 117, May 2017, pp. 118–126.

Jim, C.Y., and S.W. Tsang, 'Biophysical Properties and Thermal Performance of an Intensive Green Roof', Building and Environment, Vol. 46, No. 6, June 2011, pp. 1263–1274.

Karczmarczyk, A., A. Baryła, J. Fronczyk, A. Bus, and J. Mosiej, 'Phosphorus and Metals Leaching from Green Roof Substrates and Aggregates Used in Their Composition', Minerals, Vol. 10, No. 2, January 28, 2020, p. 112.

Knifka, W., R. Karutz, and H. Zozmann, 'Barriers and Solutions to Green Facade Implementation—A Review of Literature and a Case Study of Leipzig, Germany', Buildings, Vol. 13, No. 7, June 26, 2023, p. 1621.

Kwong, Q.J., 'Light Level, Visual Comfort and Lighting Energy Savings Potential in a Green-Certified High-Rise Building', Journal of Building Engineering, Vol. 29, May 2020, p. 101198.

Law, E.P., S.A.W. Diemont, and T.R. Toland, 'A Sustainability Comparison of Green Infrastructure Interventions Using Emergy Evaluation', Journal of Cleaner Production, Vol. 145, March 2017, pp. 374–385.

Lee, D., and C.-C. Cheng, 'Energy Savings by Energy Management Systems: A Review', Renewable and Sustainable Energy Reviews, Vol. 56, April 2016, pp. 760–777.

Lee, J., M. Boubekri, and F. Liang, 'Impact of Building Design Parameters on Daylighting Metrics Using an Analysis, Prediction, and Optimization Approach Based on Statistical Learning Technique', Sustainability, Vol. 11, No. 5, March 10, 2019, p. 1474.

LETI CEDG, London Energy Transformation Initiative's Climate Emergency Design Guide., 2020.

Lex, S.W., D. Calì, M. Koed Rasmussen, P. Bacher, M. Bachalarz, and H. Madsen, 'A Cross-Disciplinary Path to Healthy and Energy Efficient Buildings', Technological Forecasting and Social Change, Vol. 142, May 2019, pp. 273–284.

Mariano-Hernández, D., L. Hernández-Callejo, A. Zorita-Lamadrid, O. Duque-Pérez, and F. Santos García, 'A Review of Strategies for Building Energy Management System: Model Predictive Control, Demand Side Management, Optimization, and Fault Detect & Diagnosis', Journal of Building Engineering, Vol. 33, January 2021, p. 101692.

Mirabella, N., M. Röck, M. Ruschi Mendes SAADE, C. Spirinckx, M. Bosmans, K. Allacker, and A. Passer, 'Strategies to Improve the Energy Performance of Buildings: A Review of Their Life Cycle Impact', Buildings, Vol. 8, No. 8, August 12, 2018, p. 105.

Mirzaie, S., M. Thuring, and K. Allacker, 'End-of-Life Modelling of Buildings to Support More Informed Decisions towards Achieving Circular Economy Targets', The International Journal of Life Cycle Assessment, Vol. 25, No. 11, November 2020, pp. 2122–2139.

Mogas Recalde, J., R. Palau, and M. Márquez, 'How Classroom Acoustics Influence Students and Teachers: A Systematic Literature Review', Journal of Technology and Science Education, Vol. 11, No. 2, April 27, 2021, p. 245.

National Institute of Standards and Technology, 'Building Life Cycle Cost Programs', 2016. http://energy.gov/eere/femp/building- life-cycle-cost-programs.

Nwodo, M.N., and C.J. Anumba, 'A Review of Life Cycle Assessment of Buildings Using a Systematic Approach', Building and Environment, Vol. 162, September 2019, p. 106290.

OECD, Public Investment in Bulgaria: Planning and Delivering Infrastructure, OECD Public Governance Reviews, OECD, 2023.

Op't Veld, P., 'Introduction to EC RESHYVENT–EU Cluster Project on Demand Controlled Hybrid Ventilation for Residential Buildings', Building and Environment, Vol. 43, No. 8, August 2008, pp. 1342–1349.

Park, D.Y., and S. Chang, 'Effects of Combined Central Air Conditioning Diffusers and Window-Integrated Ventilation System on Indoor Air Quality and Thermal Comfort in an Office', Sustainable Cities and Society, Vol. 61, October 2020, p. 102292.

Peng, L.L.H., and C.Y. Jim, 'Economic Evaluation of Green-Roof Environmental Benefits in the Context of Climate Change: The Case of Hong Kong', Urban Forestry & Urban Greening, Vol. 14, No. 3, 2015, pp. 554–561.

Pérez, G., L. Rincón, A. Vila, J.M. González, and L.F. Cabeza, 'Green Vertical Systems for Buildings as Passive Systems for Energy Savings', Applied Energy, Vol. 88, No. 12, December 2011, pp. 4854–4859.

Pomponi, F., B. D'Amico, and A. Moncaster, 'A Method to Facilitate Uncertainty Analysis in LCAs of Buildings', Energies, Vol. 10, No. 4, April 13, 2017, p. 524.

Porras-Salazar, J.A., S. Schiavon, P. Wargocki, T. Cheung, and K.W. Tham, 'Meta-Analysis of 35 Studies Examining the Effect of Indoor Temperature on Office Work Performance', Building and Environment, Vol. 203, October 2021, p. 108037.

Poza-Casado, I., R. Gil-Valverde, A. Meiss, and M.Á. Padilla-Marcos, 'Impact of Air Infiltration on IAQ and Ventilation Efficiency in Higher Educational Classrooms in Spain', Sustainability, Vol. 13, No. 12, June 18, 2021, p. 6875.

Radić, M., M. Brković Dodig, and T. Auer, 'Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits', Sustainability, Vol. 11, No. 17, August 23, 2019, p. 4579.

Rasmussen, B., and T. Carrascal García, 'Acoustic Regulations for Offices – Comparison between Selected Countris in Europe', Institute of Noise Control Engineering, Madrid, 2019, pp. 8141–8150.

Rasmussen, F.N., B. Harpa, and M. Birkved, 'System and Scenario Choices in the Life Cycle Assessment of a Building-Changing Impacts of the Environmental Profile', Proceedings of the Sustainable Buildings - Construction Products and Technologies, 2013.

Reinhart, C.F., and O. Walkenhorst, 'Validation of Dynamic RADIANCE-Based Daylight Simulations for a Test Office with External Blinds', Energy and Buildings, Vol. 33, No. 7, September 2001, pp. 683–697.

Röck, M., M.R.M. Saade, M. Balouktsi, F.N. Rasmussen, H. Birgisdottir, R. Frischknecht, G. Habert, T. Lützkendorf, and A. Passer, 'Embodied GHG Emissions of Buildings – The Hidden Challenge for Effective Climate Change Mitigation', Applied Energy, Vol. 258, January 2020, p. 114107.

———, 'Embodied GHG Emissions of Buildings – The Hidden Challenge for Effective Climate Change Mitigation', Applied Energy, Vol. 258, January 2020, p. 114107.

Saiz, S., C. Kennedy, B. Bass, and K. Pressnail, 'Comparative Life Cycle Assessment of Standard and Green Roofs', Environmental Science & Technology, Vol. 40, No. 13, July 1, 2006, pp. 4312–4316.

Salthammer, T., E. Uhde, T. Schripp, A. Schieweck, L. Morawska, M. Mazaheri, S. Clifford, et al., 'Children's Well-Being at Schools: Impact of Climatic Conditions and Air Pollution', Environment International, Vol. 94, September 2016, pp. 196–210.

Sánchez Cordero, A., S. Gómez Melgar, and J.M. Andújar Márquez, 'Green Building Rating Systems and the New Framework Level(s): A Critical Review of Sustainability Certification within Europe', Energies, Vol. 13, No. 1, December 21, 2019, p. 66.

Satish, U., M.J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, and W.J. Fisk, 'Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance', Environmental Health Perspectives, Vol. 120, No. 12, December 2012, pp. 1671–1677.

Säynäjoki, A., J. Heinonen, S. Junnila, and A. Horvath, 'Can Life-Cycle Assessment Produce Reliable Policy Guidelines in the Building Sector?', Environmental Research Letters, Vol. 12, No. 1, January 5, 2017, p. 013001.

Scolaro TP, Ghisi E. 2022. Life cycle assessment of green roofs: A literature review of layers materials and purposes. Science of The Total Environment 829: 154650. doi: 10.1016/j.scitotenv.2022.154650

Shafique, M., A. Azam, M. Rafiq, M. Ateeq, and X. Luo, 'An Overview of Life Cycle Assessment of Green Roofs', Journal of Cleaner Production, Vol. 250, March 2020, p. 119471.

Schulze, T., and U. Eicker, 'Controlled Natural Ventilation for Energy Efficient Buildings', Energy and Buildings, Vol. 56, January 2013, pp. 221–232.

Setiati, T.W., and A. Budiarto, 'Optimization of Lighting Design in Classroom for Visual Comfort (Case Study : Universitas Tridinanti Palembang Tower)', IOP Conference Series: Earth and Environmental Science, Vol. 738, No. 1, April 1, 2021, p. 012035.

Singh, M.K., R. Ooka, H.B. Rijal, S. Kumar, A. Kumar, and S. Mahapatra, 'Progress in Thermal Comfort Studies in Classrooms over Last 50 Years and Way Forward', Energy and Buildings, Vol. 188–189, April 2019, pp. 149–174.

Soust-Verdaguer, B., C. Llatas, and A. García-Martínez, 'Simplification in Life Cycle Assessment of Single-Family Houses: A Review of Recent Developments', Building and Environment, Vol. 103, July 2016, pp. 215–227.

Stabile, L., M. Dell'Isola, A. Russi, A. Massimo, and G. Buonanno, 'The Effect of Natural Ventilation Strategy on Indoor Air Quality in Schools', Science of The Total Environment, Vol. 595, October 1, 2017, pp. 894–902.

The American Institute of architects, Buildings That Last: Design for Adaptability, Deconstruction, and Reuse., 2020.

The Carbon Leadership Forum, Life Cycle Assessment of Buildings: A Practice Guide, 2018.

Toftum, J., R. Andersen, J.J. Aguilera Prado, K. Kolstrup, D. Sloth Hauberg, and G. Clausen, 'Development of a Tool to Predict the Socio-Economic Consequences of Better Air Quality and Temperature Control in Classrooms', Energy and Buildings, Vol. 250, November 2021, p. 111274.

Toland, D.C., B.E. Haggard, and M.E. Boyer, ‘Evaluation of Nutrient Concentrations in Runoff Water from Green Roofs, Conventional Roofs, and Urban Streams’, Transactions of the ASABE, Vol. 55, No. 1, 2012, pp. 99–106.

Tran, V.V., D. Park, and Y.-C. Lee, ‘Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality’, International Journal of Environmental Research and Public Health, Vol. 17, No. 8, April 23, 2020, p. 2927.

Ürge-Vorsatz, D., N. Eyre, P. Graham, D. Harvey, E. Hertwich, Y. Jiang, C. Kornevall, et al., ‘Energy End-Use: Buildings’, in T.B. Johansson, N. Nakicenovic, A. Patwardhan, and L. Gomez-Echeverri (eds.), Global Energy Assessment (GEA), Cambridge University Press, Cambridge, 2012, pp. 649–760.

Vera, S., C. Pinto, F. Victorero, W. Bustamante, C. Bonilla, J. Gironás, and V. Rojas, ‘Influence of Plant and Substrate Characteristics of Vegetated Roofs on a Supermarket Energy Performance Located in a Semiarid Climate’, Energy Procedia, Vol. 78, November 2015, pp. 1171–1176.

Wang, J., P. Zhang, L. Yang, and T. Huang, ‘Adsorption Characteristics of Construction Waste for Heavy Metals from Urban Stormwater Runoff’, Chinese Journal of Chemical Engineering, Vol. 23, No. 9, September 2015, pp. 1542–1550.

Wang, L.M., and L.C. Brill, ‘Speech and Noise Levels Measured in Occupied K–12 Classrooms’, The Journal of the Acoustical Society of America, Vol. 150, No. 2, August 1, 2021, pp. 864–877.

Wargocki, P., J.A. Porras-Salazar, S. Contreras-Espinoza, and W. Bahnfleth, ‘The Relationships between Classroom Air Quality and Children’s Performance in School’, Building and Environment, Vol. 173, April 2020, p. 106749.

Wargocki, P., W. Wei, J. Bendžalová, C. Espigares-Correa, C. Gerard, O. Greslou, M. Rivallain, et al., ‘TAIL, a New Scheme for Rating Indoor Environmental Quality in Offices and Hotels Undergoing Deep Energy Renovation (EU ALDREN Project)’, Energy and Buildings, Vol. 244, August 2021, p. 111029.

World Health Organization. Regional Office for Europe, Combined or Multiple Exposure to Health Stressors in Indoor Built Environments: An Evidence-Based Review Prepared for the WHO Training Workshop “Multiple Environmental Exposures and Risks”, World Health Organization. Regional Office for Europe, Bonn, Germany., October 16, 2013.

Wu, J., J. Weng, B. Xia, Y. Zhao, and Q. Song, ‘The Synergistic Effect of PM2.5 and CO2 Concentrations on Occupant Satisfaction and Work Productivity in a Meeting Room’, International Journal of Environmental Research and Public Health, Vol. 18, No. 8, April 13, 2021, p. 4109.

Xiong, J., Z. Lian, X. Zhou, J. You, and Y. Lin, ‘Effects of Temperature Steps on Human Health and Thermal Comfort’, Building and Environment, Vol. 94, December 2015, pp. 144–154.

Yadav, M., D. Cabrera, J. Kim, J. Fels, and R. de Dear, ‘Sound in Occupied Open-Plan Offices: Objective Metrics with a Review of Historical Perspectives’, Applied Acoustics, Vol. 177, June 2021, p. 107943.

Yang, D., and C.M. Mak, ‘Relationships between Indoor Environmental Quality and Environmental Factors in University Classrooms’, Building and Environment, Vol. 186, December 2020, p. 107331.

Yang, D., and C.M. Mak, ‘Relationships between Indoor Environmental Quality and Environmental Factors in University Classrooms’, Building and Environment, Vol. 186, December 2020, p. 107331.

8. List of abbreviations and definitions

AC Award Criterion

AP Acidification Potential

BAMB Buildings As Material Banks

BIM Building Information Modelling

BEMS Building Energy Management Systems

BREEAM Building Research Establishment Environmental Assessment Method

BSO Building Stock Observatory

CAV Constant Air Volume

CDEW Construction, Demolition and Excavation Waste

CDW Construction and Demolition Waste

CEAP Circular Economy Action Plan

CPC Contract Performance Condition

CVRA Climate Vulnerability Risk Assessment

DBO Design-Build-Operate

DGNB Deutsche Gesellschaft für Nachhaltiges Bauen

ECSO European Construction Sector Observatory

EED Energy Efficiency Directive

EGD European Green Deal

EP Eutrophication Potential

EPBD Energy Performance of Buildings Directive

EPC Energy Performance Certificate

EPD Environmental Product Declaration

EPREL European Product Registry for Energy Labelling

GDP Gross Domestic Product

GHG Greenhouse Gas

GWP Global Warming Potential

HVAC Heating, Ventilation and Air Conditioning

IAQ Indoor Air Quality

IEQ Indoor Environmental Quality

IPCC AR6 The sixth assessment report of the Intergovernmental Panel on Climate Change

LCC Life Cycle Cost

LCA Life Cycle Assessment

NECP National Energy and Climate Plan

NZEB Nearly Zero Energy Building

ODP Ozone Depletion Potential

PEF	Product Environmental Footprint
PM	Particulate Matter
PPD	Predicted Percentage of Dissatisfied
PMV	Predicted Mean Vote
RED	Renewable Energy Directive
SC	Selection Criterion
SFP	Smog Formation Potential
TS	Technical Specification
TVOC	Total Volatile Organic Compound
VAV	Variable Air Volume
VOC	Volatile Organic Compound
WFD	Waste Framework Directive
ZEB	Zero Emission Building

Nearly Zero-Energy Building (NZEB) means a building with a very high energy performance, as determined in accordance with Annex I to the EPBD recast, which cannot be lower than the 2023 cost-optimal level reported by Member States in accordance with Article 6(2) and where the nearly zero or very low amount of energy required is covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby.

Zero-Emissions Building (ZEB) means a building with a very high energy performance, as determined in accordance with Annex I to the EPBD recast, where the very low amount of energy still required is fully covered by energy from renewable sources generated on site, from a renewable energy community within the meaning of Directive (EU) 2018/2001 or from a district heating and cooling system, in accordance with the requirements set out in Annex III of the EPBD recast.

9. List of figures

10. List of tables

11. Annexes

Annex I. List of most relevant Common Procurement Vocabulary codes

Table 20. Particularly relevant CPC and CPV codes for works and services related to building design, construction, demolition and management

Service or work description	NACE code / CPC code	CPV code
Construction work	45 /	45000000-7
Site preparation work	45.1 /	45100000-8
Building demolition and wrecking work and earthmoving work	45.11 /	45110000-1
Demolition, site preparation and clearance work	45.11 /	45111000-8
Demolition work	45.11 /	45111100-9
Site preparation and clearance work	45.11 /	45111200-0
Blasting and associated rock-removal work		45111210-3
Blasting work		45111211-0
Rock-removal work		45111212-7
Site-clearance work		45111213-4
Blast-clearing work		45111214-1
Scrub-removal work		45111220-6
Ground-stabilisation work		45111230-9
Ground-drainage work		45111240-2
Ground investigation work		45111250-5
Site-preparation work for mining		45111260-8
Primary works for services		45111290-7
Site-development work		45111291-4
Dismantling works		45111300-1
Dismantling works for military installations		45111310-4
Dismantling works for security installations		45111320-7
Excavating and earthmoving work		45112000-5
Trench-digging work		45112100-6
Soil-stripping work		45112200-7
Topsoil-stripping work		45112210-0
Infill and land-reclamation work		45112300-8
Infill work		45112310-1
Land-reclamation work		45112320-4
Site-reclamation work		45112330-7
Soil-decontamination work		45112340-0
Reclamation of waste land		45112350-3
Land rehabilitation work		45112360-6
Excavating work		45112400-9
Grave-digging work		45112410-2
Basement excavation work		45112420-5
Terracing of hillsides		45112440-1
Terracing work		45112441-8
Excavation work at archaeological sites		45112450-4

Earthmoving work		45112500-0
Cut and fill		45112600-1
Landscaping work		45112700-2
Landscaping work for green areas	45.11 /	45112710-5
Landscaping work for parks		45112711-2
Landscaping work for gardens		45112712-9
Landscaping work for roof gardens	45.11 /	45112713-6
Landscaping work for cemeteries		45112714-3
Landscaping work for sports grounds and recreational areas		45112720-8
Landscaping work for golf courses		45112721-5
Landscaping work for riding areas		45112722-2
Landscaping work for playgrounds		45112723-9
Landscaping work for roads and motorways		45112730-1
Landscaping work for airports		45112740-4
Siteworks		45113000-2
Test drilling and boring work		45120000-4
Test drilling work		45121000-1
Test boring work		45122000-8
Works for complete or part construction and civil engineering work		45200000-9
Building construction work		45210000-2
Construction work for multi-dwelling buildings and individual houses		45211000-9
Construction work for houses		45211100-0
Sheltered housing construction work		45211200-1
Houses construction work		45211300-2
Bathrooms construction work		45211310-5
Porches construction work		45211320-8
Multi-dwelling buildings construction work		45211340-4
Flats construction work	45.21 /	45211341-1
Multi-functional buildings construction work	45.21 /	45211350-7
Urban development construction work		45211360-0
Construction works for saunas		45211370-3
Construction work for buildings relating to leisure, sports, culture, lodging and restaurants		45212000-6
Construction work of leisure facilities		45212100-7
Leisure centre construction work		45212110-0
Theme park construction work		45212120-3
Amusement park construction work		45212130-6
Recreation installation		45212140-9
Cinema construction work		45212150-2

Casino construction work		45212160-5
Entertainment building construction work		45212170-8
Entertainment centre construction work		45212171-5
Recreation centre construction work		45212172-2
Ticket offices construction work		45212180-1
Sun-protection works		45212190-4
Construction work for sports facilities		45212200-8
Single-purpose sports facilities construction work		45212210-1
Ice rink construction work		45212211-8
Construction work for swimming pool		45212212-5
Sport markings works		45212213-2
Multi-purpose sports facilities construction work		45212220-4
Construction work in connection with structures for sports ground		45212221-1
Gymnasium construction work		45212222-8
Winter-sports facilities construction work		45212223-5
Stadium construction work		45212224-2
Sports hall construction work		45212225-9
Installation of changing rooms		45212230-7
Repair and maintenance work in connection with sports facilities		45212290-5
Construction work for art and cultural buildings		45212300-9
Construction work for buildings relating to exhibitions		45212310-2
Art gallery construction work		45212311-9
Exhibition centre construction work		45212312-6
Museum construction work		45212313-3
Historical monument or memorial construction work		45212314-0
Construction work for buildings relating to artistic performances		45212320-5
Auditorium construction work		45212321-2
Theatre construction work		45212322-9
Library construction work		45212330-8
Multimedia library construction work		45212331-5
Lecture hall construction work		45212340-1
Buildings of particular historical or architectural interest		45212350-4
Prehistoric monument construction work		45212351-1
Industrial monument construction work		45212352-8
Palace construction work		45212353-5

Castle construction work		45212354-2
Religious buildings construction work		45212360-7
Church construction work		45212361-4
Accommodation and restaurant buildings		45212400-0
Construction work for lodging buildings		45212410-3
Hotel construction work		45212411-0
Hostel construction work		45212412-7
Short-stay accommodation construction work		45212413-4
Construction work for restaurants and similar facilities		45212420-6
Restaurant construction work		45212421-3
Canteen construction work		45212422-0
Cafeteria construction work		45212423-7
Kitchen or restaurant conversion		45212500-1
Pavilion construction work		45212600-2
Construction work for commercial buildings, warehouses and industrial buildings, buildings relating to transport		45213000-3
Shop buildings construction work		45213110-7
Shopping centre construction work		45213111-4
Shop units construction work		45213112-1
Post office construction work		45213120-0
Bank construction work		45213130-3
Market construction work		45213140-6
Covered market construction work		45213141-3
Open-air market construction work		45213142-0
Office block construction work	45.21 /	45213150-9
Construction work for warehouses and industrial buildings		45213200-5
Cold-storage installations		45213210-8
Construction work for warehouses		45213220-1
Warehouse stores construction work		45213221-8
Abattoir construction work		45213230-4
Agricultural buildings construction work		45213240-7
Barn construction work		45213241-4
Cowsheds construction work		45213242-1
Construction work for industrial buildings		45213250-0
Industrial units construction work		45213251-7
Workshops construction work		45213252-4
Stores depot construction work		45213260-3
Construction works for recycling station		45213270-6
Construction works for compost facility		45213280-9

Buildings associated with transport		45213300-6
Construction work for buildings relating to road transport		45213310-9
Bus station construction work		45213311-6
Car park building construction work	45.21 /	45213312-3
Service-area building construction work		45213313-0
Bus garage construction work		45213314-7
Bus-stop shelter construction work		45213315-4
Installation works of walkways		45213316-1
Construction work for buildings relating to railway transport		45213320-2
Railway station construction work		45213321-9
Rail terminal building construction work		45213322-6
Construction work for buildings relating to air transport		45213330-5
Airport buildings construction work		45213331-2
Airport control tower construction work		45213332-9
Installation works of airport check-in counters		45213333-6
Construction work for buildings relating to water transport		45213340-8
Ferry terminal building construction work		45213341-5
Ro-ro terminal construction work		45213342-2
Construction work for buildings relating to various means of transport		45213350-1
Maintenance hangar construction work		45213351-8
Service depot construction work		45213352-5
Installation works of passenger boarding bridges		45213353-2
Installation of staff rooms		45213400-7
Construction work for buildings relating to education and research	45.21 /	45214000-0
Construction work for kindergarten buildings	45.21 /	45214100-1
Construction work for school buildings	45.21 /	45214200-2
Primary school construction work	45.21 /	45214210-5
Secondary school construction work	45.21 /	45214220-8
Special school construction work	45.21 /	45214230-1
Construction work for college buildings	45.21 /	45214300-3
Vocational college construction work	45.21 /	45214310-6
Technical college construction work	45.21 /	45214320-9
Construction work for university buildings	45.21 /	45214400-4
Polytechnic construction work		45214410-7
Lecture theatre construction work		45214420-0
Language laboratory construction work		45214430-3

Construction work for buildings of further education		45214500-5
Construction work for research buildings	45.21 /	45214600-6
Laboratory building construction work		45214610-9
Research and testing facilities construction work		
Scientific installations		
Installation works of cleanrooms		
Meteorological stations construction work		
Construction work for halls of residence	45.21 /	45214700-7
Entrance hall construction work		45214710-0
Training facilities building		45214800-8
Construction work for buildings relating to health and social services, for crematoriums and public conveniences		45215000-7
Construction work for buildings relating to health		45215100-8
Spa construction work		45215110-1
Special medical building construction work		45215120-4
Clinic construction work		45215130-7
Hospital facilities construction work		45215140-0
Operating theatre construction work		45215141-7
Intensive-care unit construction work		45215142-4
Diagnostic screening room construction work		45215143-1
Screening rooms construction work		45215144-8
Fluoroscopy room construction work		45215145-5
Pathology room construction work		45215146-2
Forensic room construction work		45215147-9
Catheter room construction work		45215148-6
Construction work for social services buildings		45215200-9
Construction work for subsidised residential accommodation	45.21 /	45215210-2
Retirement home construction work	45.21 /	45215212-6
Nursing home construction work	45.21 /	45215213-3
Residential homes construction work		45215214-0
Children's home construction work		45215215-7
Construction work for social facilities other than subsidised residential accommodation		45215220-5
Daycare centre construction work		45215221-2
Civic centre construction work		45215222-9
Construction work for crematoriums		45215300-0
Cemetery works		45215400-1
Public conveniences		45215500-2

Construction work for buildings relating to law and order or emergency services and for military buildings		45216000-4
Construction work for buildings relating to law and order or emergency services		45216100-5
Construction work for buildings relating to law and order		45216110-8
Police station construction work		45216111-5
Court building construction work	45.21 /	45216112-2
Prison building construction work		45216113-9
Parliament and public assembly buildings	45.21 /	45216114-6
Construction work for buildings relating to emergency services		45216120-1
Fire station construction work		45216121-8
Ambulance station construction work		45216122-5
Structures construction work	45.21 /	45223000-6
Assembly of metal structures	45.21 /	45223100-7
Installation of metal structures	45.21 /	45223110-0
Structural works	45.21 /	45223200-8
Structural steelworks	45.21 /	45223210-1
Structural shell work	45.21 /	45223220-4
Parking lot construction work	45.21 /	45223300-9
Underground car park construction work	45.21 /	45223310-2
Reinforced-concrete structures	45.21 /	45223500-1
Assembly and erection of prefabricated structures	45.21 /	45223800-4
Prefabricated constructions	45.21 /	45223810-7
Prefabricated components	45.21 /	45223822-4
Ancillary works for pipelines and cables	45.21 /	45232000-2
Ancillary works for water pipelines	45.21 /	45232100-3
Irrigation works	45.21 /	45232120-9
Irrigation piping construction work	45.21 /	45232121-6
Storm-water piping construction work	45.21 /	45232130-2
District-heating mains construction work	45.21 /	45232140-5
Heating works	45.21 /	45232141-2
Works related to water-distribution pipelines	45.21 /	45232150-8
Transformer substation	45.21 /	45232221-7
Construction and ancillary works for telephone and communication lines	45.21 /	45232300-5
Foul-water piping construction work	45.21 /	45232411-6
Drainage construction works	45.21 /	45232450-1
Drainage and surface works	45.21 /	45232451-8

Drainage works	45.21 /	45232452-5
Drains construction work	45.21 /	45232453-2
Rain-water basin construction work	45.21 /	45232454-9
Sanitary works	45.21 /	45232460-4
Roof works and other special trade construction works	45.22 /	45260000-7
Erection and related works of roof frames and coverings	45.22 /	45261000-4
Heating plant construction work	45.25 /	45251200-3
Cogeneration plant construction work	45.25 /	45251220-9
District-heating plant construction work	45.25 /	45251250-8
Special trade construction works other than roof works	45.25 /	45262000-1
Foundation work	45.25 /	45262210-6
Concrete work	45.25 /	45262300-4
Structural steel erection work for buildings	45.25 /	45262410-8
Bricklaying work	45.25 /	45262520-2
Facing brickwork	45.25 /	45262521-9
Masonry work	45.25 /	45262522-6
Miscellaneous special-trade construction work	45.25 /	45262600-7
Cladding works	45.25 /	45262650-2
Refurbishment of run-down buildings	45.25 /	45262690-4
Building alteration work	45.25 /	45262700-8
Building extension work	45.25 /	45262800-9
Balcony work	45.25 /	45262900-0
Electrical installation work	45.31 /	45310000-3
Lightning-protection works	45.31 /	45312310-3
Lift and escalator installation work	45.31 /	45313000-4
Installation of telecommunications equipment	45.31 /	45314000-1
Installation of cable infrastructure	45.31 /	45314300-4
Installation of cable laying	45.31 /	45314310-7
Installation of computer cabling	45.31 /	45314320-0
Electrical installation work of heating and other electrical building-equipment	45.31 /	45315000-8
Insulation work	45.32 /	45320000-6
Thermal insulation work	45.32 /	45321000-3
Sound insulation work	45.32 /	45323000-7
Plasterboard works	45.32 /	45324000-4
Plumbing and sanitary works	45.33 /	45330000-9
Heating, ventilation and air-conditioning installation work	45.33 /	45331000-6

Central-heating installation work	45.33 /	45331100-7
Boiler installation work	45.33 /	45331110-0
Ventilation and air-conditioning installation work	45.33 /	45331200-8
Ventilation installation work	45.33 /	45331210-1
Outdoor ventilation installation work	45.33 /	45331211-8
Air-conditioning installation work	45.33 /	45331220-4
Partial air-conditioning installation work	45.33 /	45331221-1
Installation work of cooling equipment	45.33 /	45331230-7
Installation work of refrigeration equipment	45.33 /	45331231-4
Plumbing and drain-laying work	45.33 /	45332000-3
Erection of fencing	45.34 /	45342000-6
Fire-prevention installation works	45.34 /	45343000-3
Installation of outdoor illumination equipment	45.34 /	45316100-6
Building completion work	45.4 /	45400000-1
Plastering work	45.41 /	45410000-4
Joinery and carpentry installation work	45.42 /	45420000-7
Installation of doors and windows and related components	45.42 /	45421100-5
Installation of partitioning	45.42 /	45421141-4
Installation of shutters	45.42 /	45421142-1
Installation work of blinds	45.42 /	45421143-8
Installation work of awnings	45.42 /	45421144-5
Installation work of roller blinds	45.42 /	45421145-2
Installation of suspended ceilings	45.42 /	45421146-9
Installation of partition walls	45.42 /	45421152-4
Carpentry installation work	45.42 /	45422000-1
Woodwork	45.42 /	45422100-2
Floor and wall covering work	45.43 /	45430000-0
Painting and glazing work	45.44 /	45440000-3
Other building completion work	45.45 /	45450000-6
Architectural services for buildings	86711, 86712, 86714, 86719	71221000-3
Architectural services for building extensions	86711, 86712, 86714, 86719	71223000-7
Organisation of architectural design contests	86711	71230000-9
Architectural, engineering and planning services	86711 to 86741	71240000-2
Project and design preparation, estimation of costs	86712	71242000-6
Draft plans (systems and integration)	86712	71243000-3
Calculation of costs, monitoring of costs	86711 to 86713	71244000-0
Approval plans, working drawings and specifications	86712, 86714, 86719	71245000-7

Determining and listing of quantities in construction	86712	71246000-4
Supervision of building work	86713, 86719	71247000-1
Architectural and building-surveying services	86711 to 86719	71251000-2
Structural engineering consultancy services	86721 to 86729, 86733, 86739	71312000-8
Environmental engineering consultancy services	86721, 86729	71313000-5
Noise-control consultancy services	86721, 86729	71313100-6
Sound insulation and room acoustics consultancy services	86721, 86729	71313200-7
Environmental impact assessment for construction	86721, 86729	71313400-9
Environmental indicators analysis for construction	86721, 86729	71313430-8
Environmental Impact Assessment (EIA) services for construction	86721, 86729	71313440-1
Environmental monitoring for construction	86721, 86729	71313450-4
Energy and related services	86721, 86723 to 86726	71314000-2
Electrical services	86721, 86723 to 86726	71314100-3
Energy-management services	86721, 86725	71314200-4
Energy-efficiency consultancy services	86721, 86725	71314300-5
Heating engineering services for buildings	86721, 86725	71314310-8
Building services	86711 to 86723, 86727, 86733, 86739	71315000-9
Building-fabric consultancy services	86711 to 86723, 86727, 86733, 86739	71315100-0
Building consultancy services	86711 to 86723, 86727, 86733, 86739	71315200-1
Building services consultancy services	86711 to 86723, 86727, 86733, 86739	71315210-4
Building surveying services	86722, 86727	71315300-2
Building-inspection services	86711, 86721	71315400-3
Inspection of ventilation system	86711, 86721	71315410-6
Telecommunication consultancy services	86721	71316000-6
Hazard protection and control consultancy services	86712, 86721 to 86739	71317000-3
Fire and explosion protection and control consultancy services	86721	71317100-4
Advisory and consultative engineering services	86721	71318000-0
Artificial and natural lighting engineering services for buildings	86721	71318100-1
Engineering design services for mechanical and electrical installations for buildings	86721, 86723, 86729	71321000-4
Construction economics services	86721, 86729	71321100-5
Heating-system design services	86723	71321200-6
Plumbing consultancy services	86721	71321300-7

Ventilation consultancy services	86721	71321400-8
Quantity surveying services	86722 to 86739	71324000-5
Foundation-design services	86722	71325000-2
Load-bearing structure design services	86726	71327000-6
Verification of load-bearing structure design services	86726	71328000-3
Geotechnical engineering services	86729	71332000-4
Urban planning and landscape architectural services	86741, 86742	71400000-2
Urban planning services	86741	71410000-5
Landscape architectural services	86742	71420000-8
Landscape gardening services	86742	71421000-5
Construction-related services	86711 to 86742	71500000-3
Site-investigation services	86711, 86721	71510000-6
Construction supervision services	86713 to 86719, 86727	71520000-9
Construction-site supervision services	86713 to 86719, 86727	71521000-6
Construction consultancy services	86711, 86721	71530000-2
Construction management services	86711 to 86742	71540000-5
Construction project management services	86711 to 86742	71541000-2
Technical building-inspection services	86764	71631300-3
Consulting services for water-supply and waste consultancy	86761 to 86769	71800000-6
Building-cleaning services and property management services (874)		
Land rental or sale services	82201, 82202, 82204, 82206	70320000-0
Land rental services	82201, 82202	70321000-7
Vacant-land rental or sale services	82201, 82202, 82204, 82206	70322000-4
Property management services of real estate on a fee or contract basis	82201, 82202	70330000-3
Accommodation, building and window cleaning services	94030	90911000-6
Air quality management	94090	90731100-1
Air pollution monitoring or measurement services	94090	90731400-4
Carbon dioxide monitoring services	94090	90731700-7

Source: author's own elaboration.

Annex II. Stakeholder comments by addressed Theme

Figure 37. Stakeholder comments on Theme 1: Energy consumption and greenhouse gas emissions

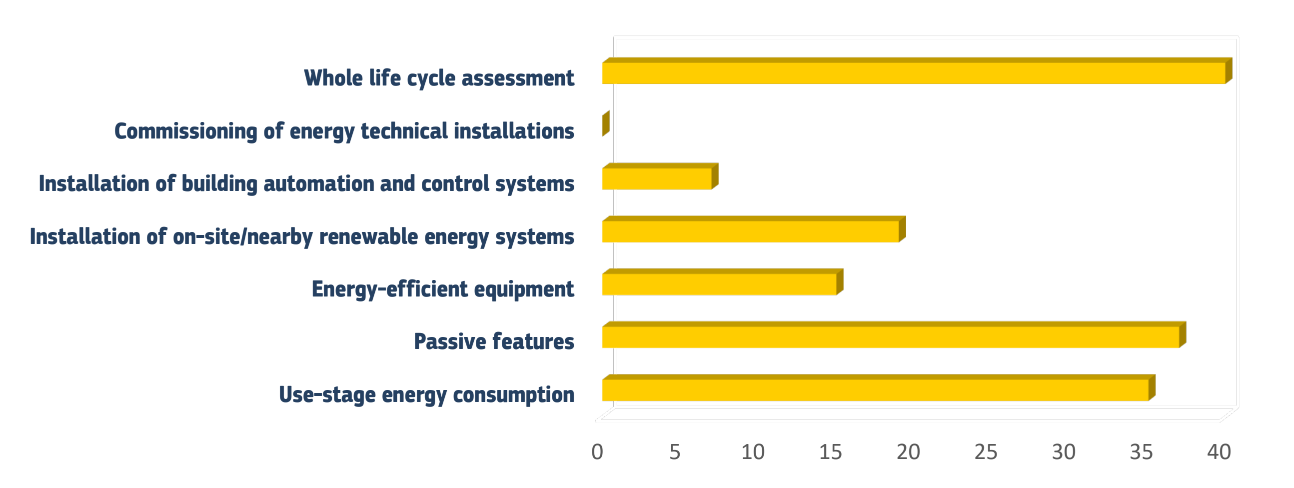


Figure 38. Stakeholder comments on Theme 2: Material circularity

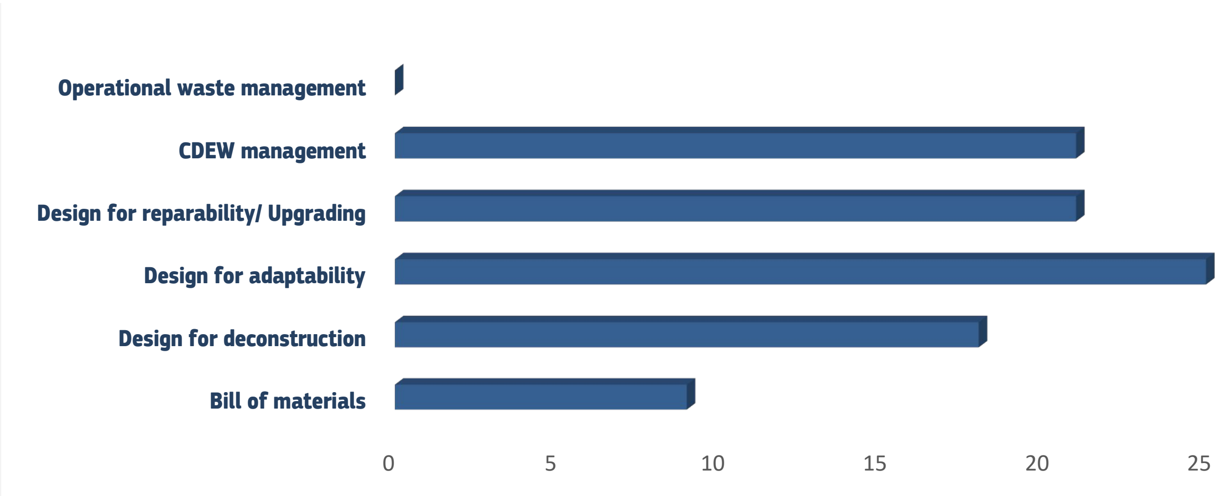


Figure 39. Stakeholder comments on Theme 3: Efficient use of water resources

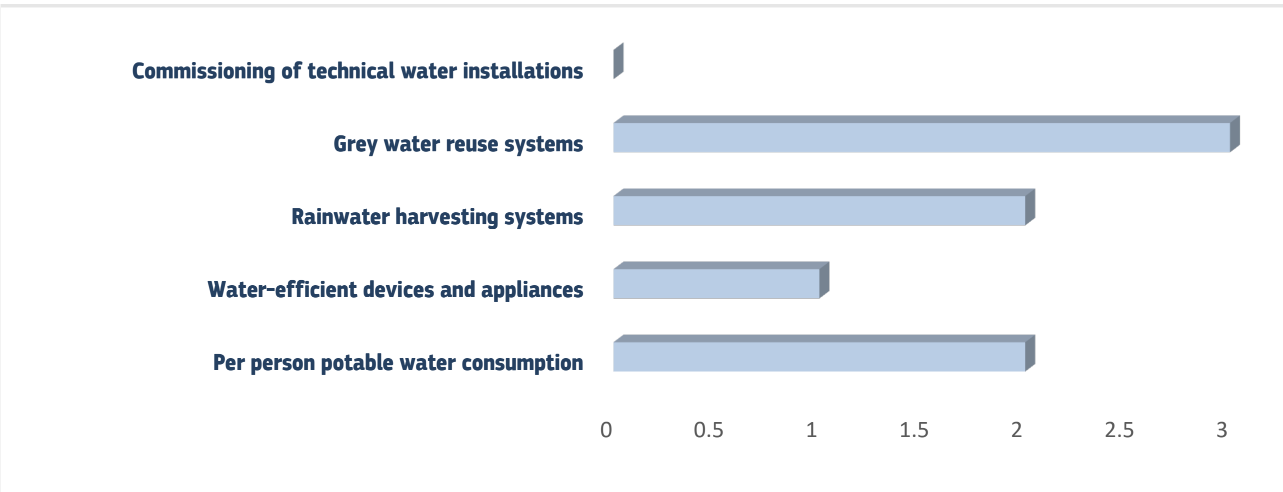


Figure 40. Stakeholder comments on Theme 4: Occupant comfort and health

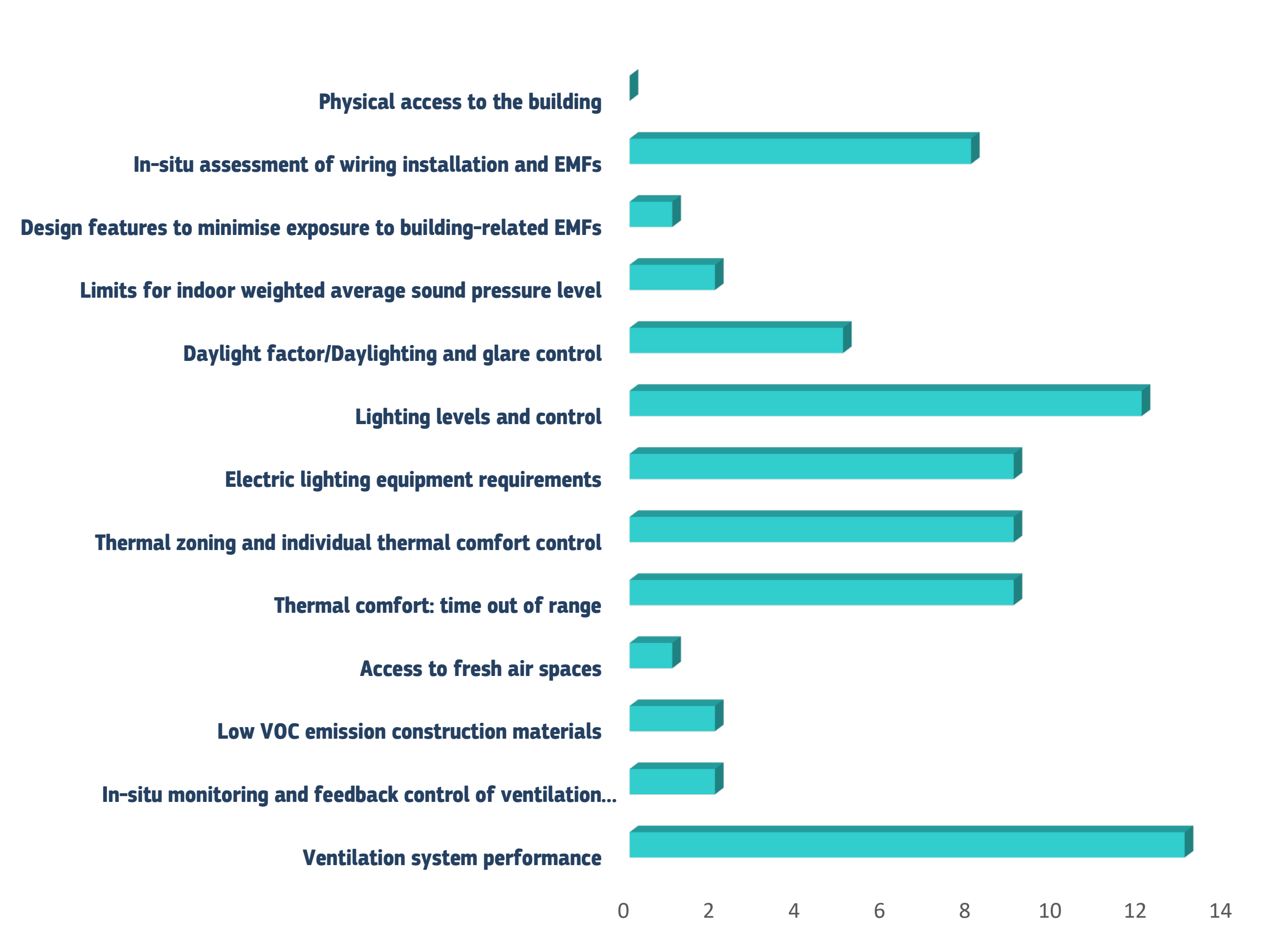


Figure 41. Stakeholder comments on Theme 5: Vulnerability and resilience to climate change

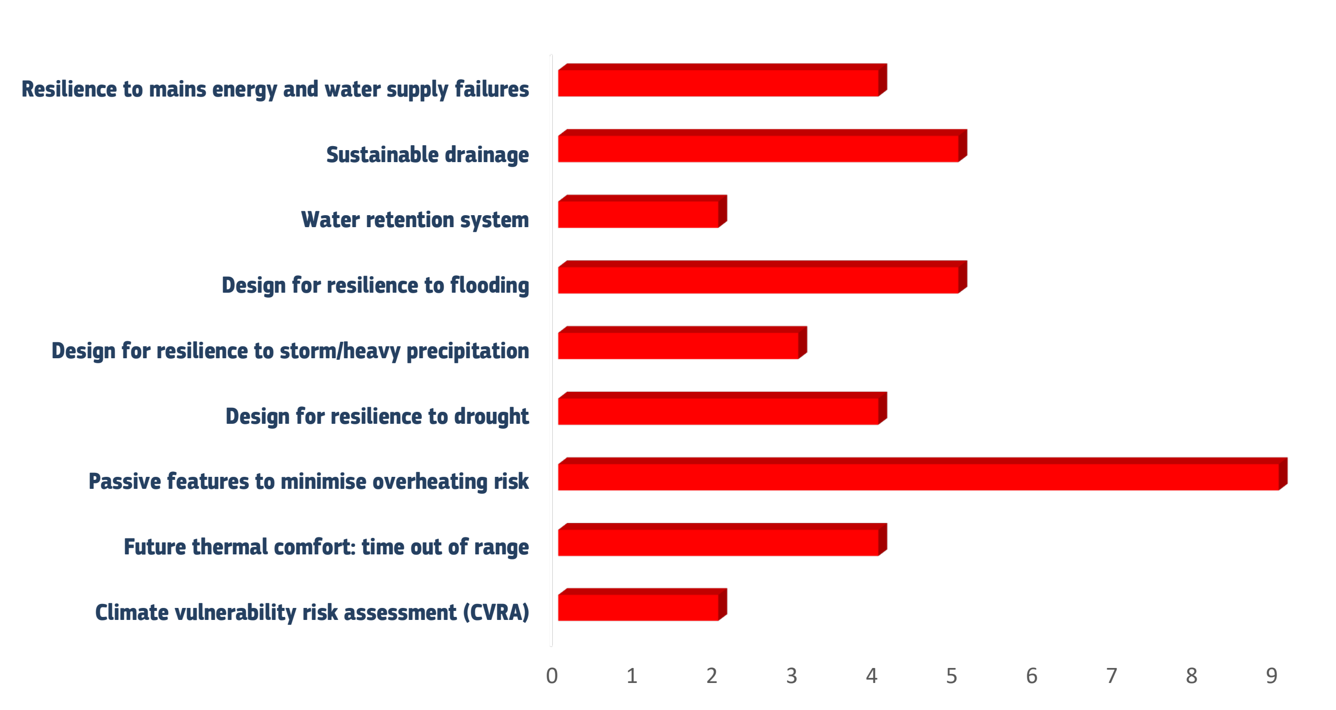
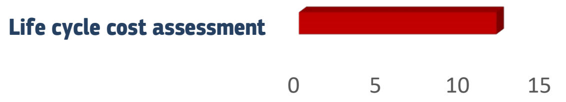
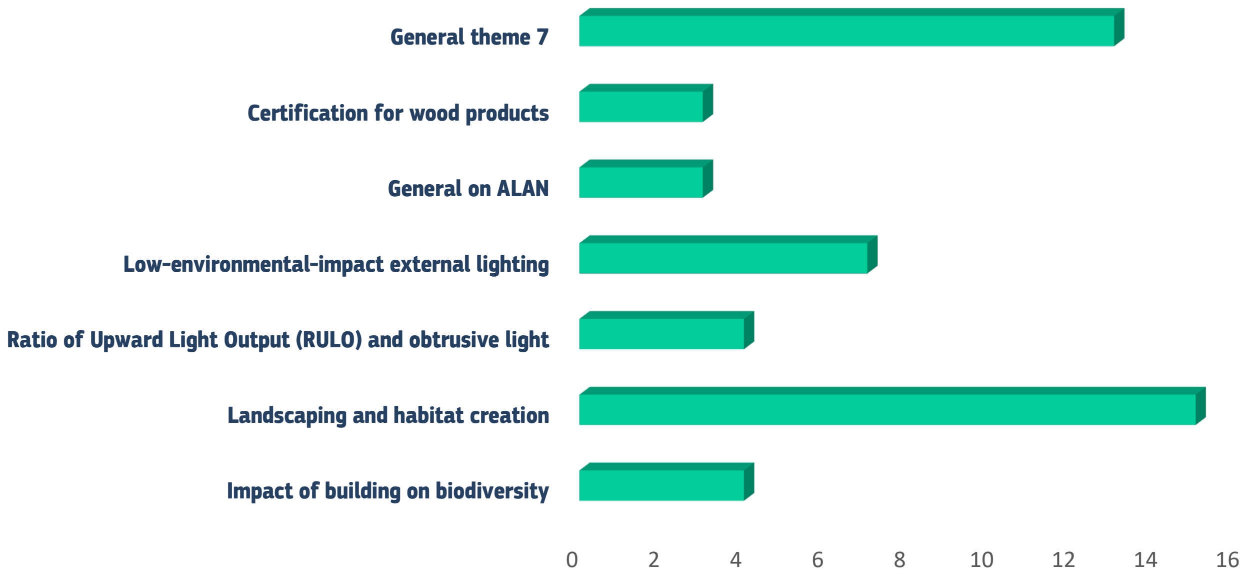


Figure 42. Stakeholder comments on Theme 6: Life Cycle Costing



Similarly to Theme 3, Theme 6 on Life Cycle Costing was not commented on in depth by stakeholders. In fact, most comments were received during the first round of consultation.

Figure 43. Stakeholder comments on Theme 7: Biodiversity



Annex III. EU GPP criteria for office buildings (2016) and Level(s) macro-objectives coverage by 3 Green Building Rating Systems

Table 21. EU GPP criteria for office buildings (2016) and Level(s) macro-objectives coverage by 3 Green Building Rating Systems

Stage	GPP criteria for office buildings	Core criteria	CC *(1)*	AC *(2)*	CPC *(3)*	Level(s) indicators	GPP sub-criteria for office buildings	VERDE construction	BREEAM construction	LEED New construction
A. Selection of the design team and contractors	A1. Competencies of the project manager	*	*							*
	A2. Competencies of the design team	*	*					*	*	*
	A3. Competencies of the main construction contractor and specialist contractors.	*	*							*
	A4. Competencies of DBO contractors and property developers	*	*							*
	A5. Energy Management System	*								
B. Detailed design and performance requirements	B1. Minimum Energy performance	*	*			**1.1 Use stage energy performance**	Minimum class of Energy Performance Certificate (EPC)	*	*	*
							Dynamic thermal simulation model	*	*	*

B2. Lighting control systems		*		**4.3 Lighting and visual comfort**	Lamps and lighting design	*	*	*
					Fitting occupancy sensors			*
					Occupiers able to control lighting systems in zones	*		*
B3. Building energy management system	*		*		Fitting a BEMS	*	*	*
					Easy user interface providing information	*	*	
					Occupants able to adjust comfort conditions in zones	*	*	
					Technical systems (HVAC, lighting, etc.) controlled by occupants	*	*	
					The BEMS offers additional capabilities	*		
B4. Low or zero carbon energy sources	*		*		Connexion of the building to renewable energy systems		*	*
					A minimum of 10% primary energy with renewables			*
					Additional primary energy from renewables			*
B5. Staff travel plan and infrastructure	*		*		Staff travel plan to reduce commuting	*	*	*
					Accessible bicycle storage	*	*	*
					Electric recharging points for electric vehicles and e-bikes	*	*	*
B5. Recyclable waste storage		*			Waste storage space for segregation	*	*	*
B6. Water saving installations		*		**3.1 Use stage water consumption**	Water-efficient fittings in sanitary and kitchen facilities	*	*	*

B7.1 Thermal comfort conditions	*	*		**4.2 Time out of thermal comfort range**	Indoor temperature in accordance with EN 15251	*	*	*
					Dynamic thermal simulation modelling		*	
B7.2 Daylighting and glare control	*	*		**4.3 Lighting and visual comfort**	Daylight Factor	*	*	*
					Control measures for glare	*	*	*
					Dynamic modelling	*	*	*
B7.3 Ventilation and air quality	*	*		**4.1 Indoor Air Quality**	Indoor Air Quality in accordance with EN 15251			
					Ventilation system filters		*	
					No air intake positioned on facades facing busy roads		*	*
					Air intakes located 20 m from poor air quality sources			
B8.1 Minimum Energy performance requirements			*	**1.1 Use stage energy performance**				
B8.2 Building life cycle GWP			*	**1.2 Life cycle Global Warming Potential**	Low Global Warming Potential	*	*	
B9. Low or zero carbon energy sources			*	**1.2 Life cycle Global Warming Potential**				
B10.1 Performance of the main building elements: Aggregation of Environmental Product Declarations (EPDs)			*			*	*	*
B10.2 Incorporation of recycled content in concrete and masonry			*		15% of recycled content	*	*	
					30% of recycled content	*	*	

	B10.3 Performance requirements for CO2e emissions from the transportation of aggregates				*						
C. Strip-out, demolition and site preparation works	C1. Demolition waste audit and management plan	*		*			**2.2 Construction & demolition waste and materials**	Reuse of 55% of non-hazardous demolition waste	*	*	
								Reuse of 80% of non-hazardous demolition waste	*	*	
								Pre-demolition/strip-out audit	*	*	
D. Construction of the building or major renovation works	D1. Sourcing of legal timber by the lead construction contractor		*					Legally harvested timber	*	*	
	D2. Installation and commissioning of building energy systems		*					Functional performance testing routine	*		
	D3. Site waste management	*		*			**2.2 Construction & demolition waste and materials**	Waste arising ≤ 11 tonnes per 100 m^2	*		*
								Waste arising ≤ 7 tonnes per 100 m^2	*		*
								Waste management plan	*	*	*
								Identifying waste prevention opportunities	*		*
	D4. Selection of fit-out materials and finishes	*		*				Compliance emission limits in Table E of GPP criteria	*	*	*
								Compliance emission limits in Table G of GPP criteria	*	*	*
	D5. Installation and commissioning of building energy systems					*		n/a			
	D6. Incorporation of recycled content					*		Verification of recycled content	*	*	

	D7. Sourcing of legal timber; Sustainable Sourcing of Timber				*		n/a			
	D8. Site waste management				*	**2.2 Construction & demolition waste and materials**	n/a			
E. Installation of energy systems and the supply of energy services	E1. Heating systems, including Combined Heat and Power (CHP)	*	*			**1.1 Use stage energy performance**				
F. Completion and handover	F1. Quality of the completed building fabric	*	*				Air tightness	*	*	*
	F2. Installation and commission of low or zero carbon energy sources			*			Aftercare service and Low or zero carbon energy commissioning			
	F3. Quality of the completed building fabric				*		n/a			
	F4. Lighting control systems				*	**4.3 Lighting and visual control**	GPP criteria for indoor lighting commissioning	*		*
	F5. Building energy management system				*	**1.1**	BEMS commissioning			
	F6. Installation and commissioning of low or zero carbon energy sources				*	**1.2**	n/a			
	F7. Recyclable waste storage				*		Storage space for waste segregation	*	*	*
	F8. Air quality testing				*	**4.1 Indoor Air Quality**	Air quality testing	*		*
G. Facilities management	G1. Building energy management system	*	*			**1.1 Use stage energy performance**	BEMs monthly reports	*	*	*

				Results per zone and energy-saving recommendations	*	
G2. Energy performance contract	*			Energy performance contract agreement	*	*
				Data verification	*	*
G3. Waste management system	*	*		Systems to segregate waste arising by occupiers		*
				Verifying the waste segregation system		*
				Monitoring and quantification of waste arising		*
G4. Energy performance contract			*	n/a		
G5. Waste management system			*	n/a		

(1) CC: Core Criteria
(2) AC: Award Criteria
(3) *CPC: Contract Performance Condition*

Source: Adapted from Sánchez Cordero, Gómez Melgar, and Andújar Márquez, (2019).

Annex IV. Use of Level(s) inside the final revised EU GPP criteria for Buildings

The purpose of this table is to show the use of Level(s) throughout the EU GPP criteria revision process, as well as to visualise the applicability of the criteria to both, functionality and typology of building projects. As can be seen, 13 of the 16 Level(s) indicator have been used. In addition, it has been substantiated why in certain cases the approach in the design of the criteria does not consider Level(s).

<table>
<tr><th colspan="6">THEME 1 – ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS</th></tr>
<tr><th colspan="3">CRITERION</th><th rowspan="2">LEVEL (S) ELEMENT USED</th><th rowspan="2">BUILDING PROJECT (1)</th><th rowspan="2">BUILDING FUNCTIONALITY (2)</th></tr>
<tr><th>Type</th><th>Number</th><th>Name</th></tr>
<tr><td rowspan="6">TECHNICAL SPECIFICATIONS</td><td>TS 1.1.1</td><td>Use-stage energy consumption</td><td>Level(s) indicator 1.1</td><td>Specific requirements for C, R</td><td rowspan="10">E/R/O</td></tr>
<tr><td>TS 1.1.2</td><td>Passive features</td><td rowspan="4">No mention is made to Level(s) since the criterion does not require the definition of any indicators</td><td rowspan="9">C/R</td></tr>
<tr><td>TS 1.1.3</td><td>Energy-efficient HVAC, lighting, water heating and other building equipment</td></tr>
<tr><td>TS 1.1.4</td><td>Installation of on-site or nearby renewable energy systems</td></tr>
<tr><td>TS 1.1.5</td><td>Installation of building automation and control systems</td></tr>
<tr><td>TS 1.2</td><td>Preliminary Whole Life Cycle Assessment</td><td>Level(s) indicator 1.2</td></tr>
<tr><td rowspan="3">AWARD CRITERIA</td><td>AC 1.1.3</td><td>Energy-efficient HVAC, lighting, water heating and other building equipment</td><td rowspan="2">No mention is made to Level(s) since the criterion does not require the definition of any indicators</td></tr>
<tr><td>AC 1.1.4</td><td>Installation of on-site or nearby renewable energy systems</td></tr>
<tr><td>AC 1.2</td><td>Preliminary Whole Life Cycle Assessment</td><td>Level(s) indicator 1.2</td></tr>
</table>

(1) C: Construction and R: renovation

(2) E: educational building, R: residential building and O: office building

THEME 2 – MATERIAL CIRCULARITY					
CRITERION			**LEVEL (S) ELEMENT USED**	**BUILDING PROJECT** *(1)*	**BUILDING FUNCTIONALITY** *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 2.1	Bill of materials	Level(s) indicator 2.1 excel-based calculation spreadsheet.	C/R	E/R/O
	TS 2.2	Design for deconstruction	Level(s) indicator 2.4 excel-based calculation spreadsheet.		
	TS 2.3	Design for adaptability	Level(s) indicator 2.3 excel-based calculation spreadsheet.		
	TS 2.5.1	CDEW management Plan	Level(s) indicator 2.2 excel-based calculation spreadsheet		
AWARD CRITERIA	AC 2.4	Design for reparability and upgrading	Not addressed in Level(s)		
	AC 2.6	Operational waste management plan			
CONTRACT PERFORMANCE CONDITIONS	CPC 2.5.2	Log waste	Level(s) indicator 2.2 excel-based calculation spreadsheet.	C/R	

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

THEME 3 - EFFICIENT USE OF WATER RESOURCES					
CRITERION			**LEVEL (S) ELEMENT USED**	**BUILDING PROJECT** *(1)*	**BUILDING FUNCTIONALITY** *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 3.1	Per person potable water consumption	Level(s) methodology (indicator 3.1) excel-based calculation spreadsheet.	C/R	Specific requirements for E/R/O
	TS 3.2	Water-efficient devices and appliances	Not addressed in Level(s)		E/R/O
	TS 3.3	Rainwater harvesting systems			

	TS 3.4	Grey water reuse systems			
CONTRACT PERFORMANCE CONDITIONS	CPC 3.5.1	Verification of compliance of the installed system	No mention is made to Level(s) since the criterion does not require the definition of any indicators		

THEME 4 - OCCUPANT COMFORT AND WELLBEING					
CRITERION			**LEVEL (S) ELEMENT USED**	**BUILDING PROJECT** *(1)*	**BUILDING FUNCTIONALITY** *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 4.1.1	Ventilation system performance	Methodology in Level(s) User's manual for indicator 4.1	C/R	Specific requirements for E, R, O
	TS 4.1.2	In-situ monitoring and feedback control of ventilation performance	No mention is made to Level(s) since the criterion does not require the definition of any indicators		E/R/O
	TS 4.1.3	Low Volatile Organic Compound (VOC) emission construction materials	No mention is made to Level(s) since the thresholds have been defined according to standards, mentioned in Level(s) user manual for indicator 4.1.		
	TS 4.2.1	Thermal comfort: time out of range	Methodology in Level(s) User's manual for indicator 4.2		
	TS 4.2.2	Thermal zoning and individual thermal comfort control	No mention is made to Level(s) since the criterion does not require the definition of any indicators		
	TS 4.3.1	Electric lighting equipment requirements	Criteria in TS 4.3.1, 4.3.2 and 4.3.3 are mostly set based on recommended thresholds in standards because Level(s) indicator 4.3 does not set thresholds.		
	TS 4.3.2	Lighting levels and control			
	TS 4.3.3	Daylight factor and glare control			Specific requirements for E/R/O
	TS 4.4.1	Limits for indoor weighted average sound pressure level	Requirements are set based on recommended thresholds in scientific literature and standards. The Level(s) indicator 4.4 is not fully developed yet as indicated in the BR.		
	TS 4.5	Physical access to the building and its services	Not addressed in Level(s)		E/R/O

AWARD CRITERIA	AC 4.1.1	Ventilation system performance	No mention is made to Level(s) since the criterion does not require the definition of any indicators		

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

THEME 5 - VULNERABILITY AND RESILIENCE TO CLIMATE CHANGE					
CRITERION			**LEVEL (S) ELEMENT USED**	**BUILDING PROJECT** *(1)*	**BUILDING FUNCTIONALITY** *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 5.1	Climate Vulnerability Risk Assessment (CVRA)	Partially addressed in Level(s), however this criterion has been developed according to the EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu) published by DG CLIMA in 2023, for being more comprehensive and updated	C/R	E/R/O
	TS 5.2.1	Future thermal comfort: time out of range	Methodology in Level(s) user's manual for indicator 4.2 and 5.1		
	TS 5.2.2	Passive features to minimise overheating risk	This criterion has been developed according to the EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu) published by DG CLIMA in 2023, for being more comprehensive and updated		
	TS 5.3	Design for resilience to drought			
	TS 5.4	Design for resilience to storm/heavy precipitation	Partially addressed in Level(s), however this criterion has been developed according to the EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu) published by DG CLIMA		
	TS 5.5.1	Design for resilience to flooding			

			in 2023, for being more comprehensive and updated		
	TS 5.6	Sustainable drainage	To keep the coherence among this theme, this criterion has been developed according to the EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu) published by DG CLIMA in 2023, for being more comprehensive and updated		
AWARD CRITERIA	AC 5.5.2	Water retention system	This criterion has been developed according to the EU-level technical guidance on adapting buildings to climate change - Publications Office of the EU (europa.eu) published by DG CLIMA in 2023, for being more comprehensive and updated		

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

THEME 6 - LIFE CYCLE COSTING					
CRITERION			**LEVEL (S) ELEMENT USED**	**BUILDING PROJECT** *(1)*	**BUILDING FUNCTIONALITY** *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 6.1	Preliminary Life Cycle Cost assessment	The life cycle cost data should be reported following Level(s) indicator 6.1	C/R	E/R/O

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

THEME 7 - BIODIVERSITY

CRITERION			LEVEL (S) ELEMENT USED	BUILDING PROJECT *(1)*	BUILDING FUNCTIONALITY *(2)*
Type	**Number**	**Name**			
TECHNICAL SPECIFICATIONS	TS 7.1.1	Landscaping and habitat creation	Not addressed in Level(s)	C/R	E/R/O
	TS 7.1.2	Green roofs			
	TS 7.1.3	Green walls			
	TS 7.2.1	Artificial light at night (ALAN)			
	TS 7.2.2	Low-environmental-impact external lighting			
	TS 7.3	Chain of custody for wood products in buildings			

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

CRITERION			LEVEL (S) ELEMENT USED	BUILDING PROJECT *(1)*	BUILDING FUNCTIONALITY *(2)*
Type	**Number**	**Name**			
SELECTION CRITERIA	SC1	Competencies of the project manager	Not addressed in Level(s)	C/R	E/R/O
	SC2	Competencies of the design team	Not addressed in Level(s)		
	SC3	Competencies of the main construction contractor and specialist contractors	Not addressed in Level(s)		
	SC4	Competencies of Design-Build-Operate (DBO) contractors	Not addressed in Level(s)	C/R	
	SC5	Energy Management System	Not addressed in Level(s)		

(1) C: Construction and R: renovation
(2) E: educational building, R: residential building and O: office building

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.