BUILDINGS & CITIES

Lützkendorf, T., & Frischknecht, R. (2020). (Net-) zero-emission buildings: a typology of terms and definitions. *Buildings and Cities*, 1(1), pp. 662–675. DOI: https://doi.org/10.5334/bc.66

SYNTHESIS

(Net-) zero-emission buildings: a typology of terms and definitions

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Abstract

Several different definitions of 'net-zero' or 'climate-neutral' buildings have arisen and are causing confusion. Different approaches quantify the greenhouse gas (GHG) emissions of buildings over their life-cycle. A typology is proposed based on distinctions between absolute and net-zero-emission buildings in relation to operational and full life-cycle approaches. Besides the absolute zero-emission approach, three different net-zero-emission approaches are: (1) a net-balance approach, which includes credits caused by potentially avoided emissions beyond the system boundary provided by exported energy; (2) an offsetting approach, based on the purchase of CO_2 certificates; and (3) a technical approach, based on negative-emission technologies. The declaration of the approach chosen will provide clarity when discussing (net/absolute)-zero emission or climate-neutral buildings.

Policy relevance

The use of suitable terms, definitions, system boundaries as well as calculation and assessment rules is a prerequisite for credibility and transparency. Legal requirements for limiting GHG emissions from buildings and their fulfilment should therefore be formulated in a way that is understandable by both industry professionals and stakeholders with clear rules for documentation and the provision of evidence. This is particularly important for the proof of the political goal to create a climate-neutral building stock. A typology of (net-) zero building approaches is presented that explains their level of ambition, fosters transparency, and reduces misperceptions and misunderstandings.

Keywords: buildings; climate neutral; definition; greenhouse gas emissions; life-cycle assessment; net zero; zero emission

1. Introduction

Various reports have been published on the need to limit global warming in the interests of preserving the natural resources of humanity (*e.g.* IPCC 2018a). The 2015 Paris Agreement requires countries to commit to keep the temperature increase significantly <2°C (UN 2015). However, clarity is needed for the definitions of suitable measurement, reference values, specific target setting and mitigation actions for greenhouse gas (GHG) emissions. A wide variety of terms exist to formulate this goal of keeping within a 1.5–2.0°C rise, but they lack clarity, offer room for interpretation and lack clear references to specific basic principles, system boundaries, as well as calculation and assessment rules. This creates uncertainty and risk. Unclear terms and definitions in combination with a broad scope for interpretation undermine transparency and credibility.

How one determines the influences and impacts on the climate or its change raises several initial questions. Different variables may qualify to monitor the development to stay below the 2.0 or 1.5°C target:

(a) Concentration of CO_2 in the atmosphere
(b) Concentrations of other GHGs in the atmosphere
(c) Anthropogenic emissions from fossil carbon
(d) Anthropogenic emissions of fossil CO_2
(e) Anthropogenic emissions of GHGs.

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While (a) and (b) can be measured, values for (c) to (e) are usually calculated. It is important to know whether either only CO_2 or all GHG emissions are taken into account. There are cases in which CO_2 neutrality is achieved without this also being the case for all GHGs (climate neutrality). This fact shows the high importance of transparent calculation and modelling rules and system boundary.

A transparent process can ascertain the variety of emission sources and their climate impacts. The extent of the following sources needs to be taken into account:

- Emissions associated with energy conversion (combustion), called energy-related emissions
- Process-related emissions
- Contributions from land use and land-use change
- Biogenic carbon
- Synthetic gases such as hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride (also called F-gases).

The public debate is informed by the use of a diversity of terms; some are clearly explained and defined, but others not. The variety of terms in combination with a lack of clarity or transparency undermines the acceptance, trust and credibility of environmental assessments of buildings in general. **Table 1** shows examples of terms used by companies, public authorities and organisations applied on buildings, neighbourhoods and districts, institutional, regional or national building stocks (operated by private or public building owners).

The terms using 'neutral' and 'zero' in **Table 1** may be combined with 'nearly' to indicate the proximity to the target without defining it exactly or with 'net' in case GHG emissions are determined using a kind of balancing approach.[1] The addition 'net' is thus the alternative to 'absolute' neutrality or 'absolute' zero emissions.

The question about the appropriate definition of a 'zero' and the level and extent to which compensation measures are part of such a definition is considered important.

The aim of this paper is to offer a typology of terms related to the life-cycle-based GHG emissions of buildings and, in particular, their zero and net-zero levels. This typology characterises current approaches based on their terms, definitions, calculation and modelling rules as well as options for compensations. The intention is to increase the transparency and understanding and thus the credibility of current approaches. The main questions are:

- What are the main differences between zero-emission and net-zero-emission approaches?
- Why it is considered important to distinguish between these two main approaches?
- What options exist to reach net-zero-emission buildings?
- What are their main conceptual differences of the net-zero-emission approaches?

The typology offered here is based on the authors' experiences in international (ISO TC 59 and SC 17[2]); and European standardisation work (CEN TC 350[3]); in international research projects (e.g. IEA EBC Annex 57[4] and IEA EBC Annex 72[5]), as well as national harmonisation and consensus-finding processes.

The paper is structured as follows. After a short description of a building and its life-cycle as object of investigation, the principles and steps of a GHG emission balance are explained. This is followed by the development of a systematic approach to terms and system boundaries for (net-) zero-emission approaches. A proposal is then presented for communicating the climate-protection goals and approaches, including the latest developments in international standardisation.

2. Object of investigation: an individual building

In view of calculating, analysing, assessing and finally reducing the life-cycle-based GHG emissions of an individual building, the building and its life-cycle needs to be modelled, calculation and modelling rules need to be formulated, and further questions need to be answered.

Table 1: Frequently used terms to describe low or zero carbon approaches to buildings.

Climate change	Greenhouse gas (GHG) emissions	Carbon
Climate friendly	CO_2 neutral	Carbon neutral
Climate neutral	GHG neutral	
Climate positive	Zero GHG emissions	
Paris compatible		
Below 2°C compatible		

2.1 Structure of a building's life-cycle

It is useful and common practice to define the type and pattern of use of a building based on a description of a functional equivalent, to check the completeness of the building model and to structure the building's life-cycle. This is usually performed by defining life-cycle stages and then attributing specific information to each stage, using information modules. This structure is proposed by the relevant international and European standards (CEN 2011). An important distinction can be made between building-related parts, including production, construction, maintenance and replacement, and end of life (embodied) and operation-related parts of the life-cycle (**Figure 1**).

The GHG emissions of individual building can be structured according to the two parts proposed in **Figure 1**:

- Operational emissions/impacts (heating/cooling, hot water supply, ventilation/cooling, lighting, auxiliary energy demand) lead to efforts to reduce the energy demand and of decarbonising the energy supply. It is proposed to structure building-related operational energy demand into regulated, non-regulated, and user and use-specific energy demand, following ongoing discussions in the current European standardisation process in CEN/TC 350. Furthermore, mobility-induced energy demand (*e.g.* electricity for battery charging of electric cars) may be added. This distinction is helpful in transparently reporting the scope of operational energy consumption covered in the assessment.
- Embodied emissions/impacts, caused during the manufacture of construction materials and building components/elements, the transport and construction process, maintenance, replacement and end of life.

Thus, building-related GHG emissions can be structured as follows:

- Operational (represented by the blue dashed line in **Figure 1**)[6]
- Embodied (production, construction, maintenance, replacement and end of life) (represented by the tan dashed line in **Figure 1**)
- Whole-life emissions: a combined life-cycle approach to the above in order to provide a 'big picture' view (represented by the black dashed line in **Figure 1**).

2.2 Quantifying and assessing GHG emissions of individual buildings

To achieve climate-neutral buildings in line with strategies for a fulfilment of the Paris Agreement, the GHG emissions caused during the life-cycle of a building should be zero. Today, zero direct GHG emissions during the operation of buildings and thus absolute zero operational GHG emissions are feasible using renewable energy. Today, GHG are

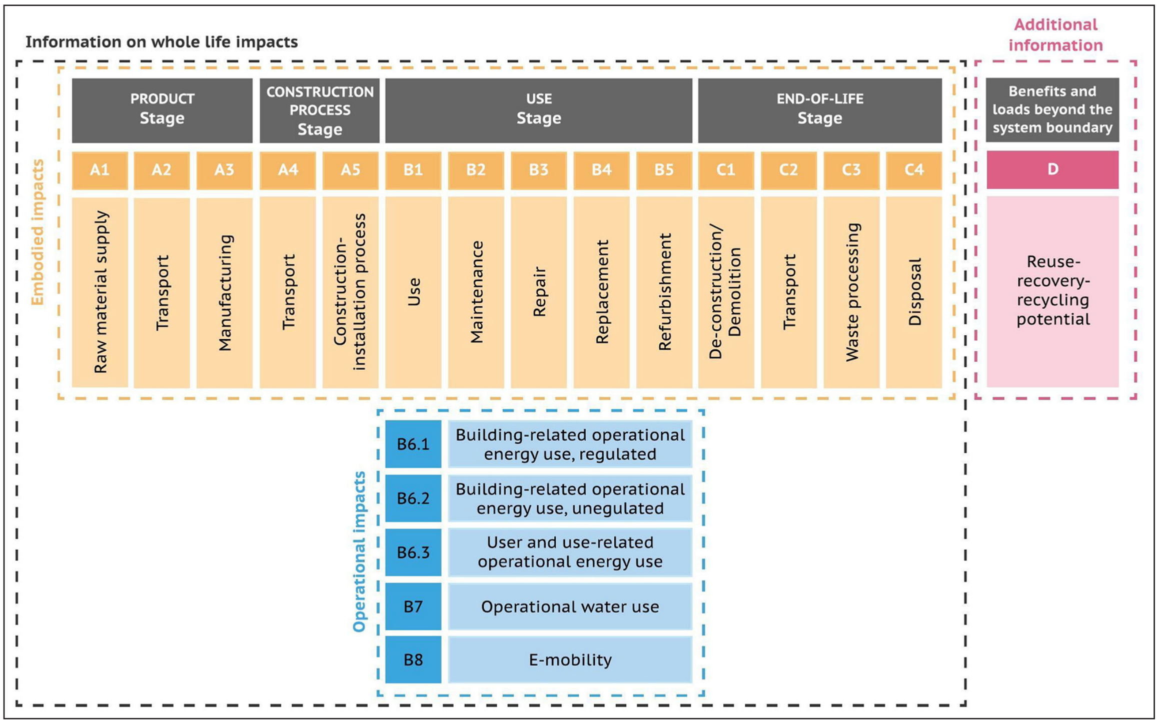

Figure 1: Life-cycle stages of a building, distinguishing the different boundaries (dotted) between the impacts arising from embodied and operational aspects.

Source: Modified from EN 15978 (CEN 2011) in combination with Lützkendorf (2019).

still emitted in the supply chains of the renewable energies as well as in construction material and building element manufacture. Thus, zero life-cycle-based GHG-emission buildings are yet difficult to achieve. Some kind of GHG emission reductions need to be included in the GHG emissions assessment of buildings (**Figure 2**). There are three options for such emission reductions: (A) a net balance with potentially avoided emissions beyond the system boundary of the building; (B) the purchase of CO_2 certificates issued by organisations investing in GHG emission reduction projects; or (C) negative emissions based on technical measures that extract CO_2 from the atmosphere.

Emissions and emission reductions can be assessed for direct operational, direct and indirect operational and for full life-cycle-based GHG emissions of buildings. The scope of the analysis and the system boundary need to be identical for the assessment of the emissions and the emission reductions. Below are examples of questions related to the scope and system boundary for both sides (emissions and emission reductions):

- *Emissions side*
  Which kinds of energy consumption during operation (modules B6.1–6.3, B7, B8) (**Figure 1**) should be included as a basis for the calculation of energy-related GHG emissions? Which parts of the building should be included to determine the embodied GHG emissions? What kind of non-energy-related GHG emissions are included? Answers to these questions help to define the scope of the model used to quantify the GHG emissions of buildings. At the same time they define the scope for the GHG emission reductions. On the emission reductions side, additional questions need to be answered.

- *Emission reductions side*
  Which of the three emission reductions approaches should be applied? Is it possible or feasible to combine the three approaches? Are they equivalent in terms of the effectiveness of contributing to the achievement of the Paris Agreement? Should a safety margin be applied to the total amount of GHG emissions to ensure net-zero GHG emissions given the uncertainties in the life-cycle assessment (LCA) data?

In the following section, some key elements of scope and system boundary definition are described in more detail.

2.3 Checklist for the scope definition of buildings

In the context of life-cycle-based GHG emissions of buildings and the preparation of a building-specific GHG emission balance, a few questions need to be clarified.

2.3.1 Quantifying GHG emissions

Life-cycle-based GHG emissions caused by buildings cannot be measured. They can be calculated using an environmental life-cycle assessment. The GHG emissions caused during the operation of buildings are calculated based on the demand

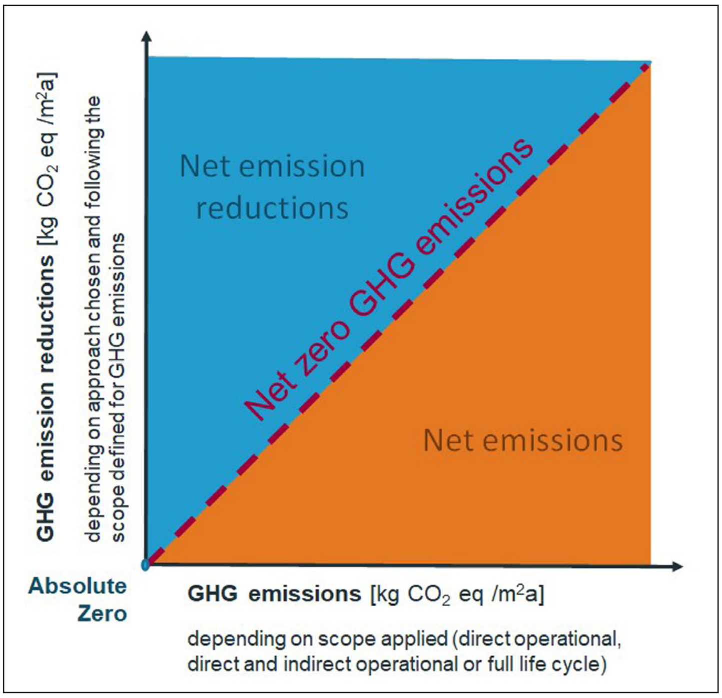

Figure 2: Greenhouse gas (GHG) emissions, GHG emission reductions and resulting net-zero GHG emissions.
Note: GHG emission reductions may be based on potentially avoided emissions beyond the system boundary, the purchase of CO_2 emissions certificated or investments in negative-emission technologies (NET) (see section 3).
Source: Adapted from Musall (2013).

of the final energy carriers and their supply chain-based GHG emission factors. These emission factors may be average or project specific and either static (representing the actual situation) or dynamic (including future developments in the energy and electricity mixes). The operational GHG emissions may also cover process-specific emissions such as leakages of refrigerants used in electric heat pumps.

The embodied GHG emissions caused during the manufacture of construction materials and building elements, construction and end of life (demolition, waste management, disposal) of the building are determined based on the quantity of materials and by taking into account building element-specific lifetimes. Average (generic) data offered by associations, public authorities or LCA database operators or specific LCA data offered by manufacturers are used (*e.g.* KBOB *et al.* 2016; Saint-Gobain ISOVER 2014; Stahlbau Zentrum Schweiz 2014). The availability of sufficient and appropriate data in view of their geographical, temporal and technological representativeness is a necessary although not a sufficient prerequisite.

2.3.2 Defining appropriate system boundaries

The description of the object of investigation is one important prerequisite for the appropriate quantification, assessment and reduction of GHG emissions. This is important to ensure that there is neither double-counting nor exclusion. The definition includes the object of investigation itself and the system boundary. In the case of buildings: (1) the object of assessment is described and quantified based on the description of the functional equivalent (sometimes also called a functional unit and expressing the functional requirements as a basis for the reference unit and a basis for comparisons); and (2) the system boundary is defined, which allows for and requires a complete quantification of the construction works and its parts as well as the complete life-cycle, ideally structured according to stages and information modules, defined in international and European standards (*e.g.* CEN 2011).

The definition of the scope may have a substantial influence on the total amount of GHG emitted during the life-cycle of a building, for instance, regarding the kinds of operational energy taken into account, see above).

2.3.3 Selecting appropriate indicators

The quantification of only CO_2 emissions alone is insufficient as some construction products, energy carriers, heating and cooling devices emit substantial amounts of other GHGs such as methane, nitrous oxides and refrigerants. It is very common to assess GHG emissions with the most recent global warming potentials (GWP 100) of the various GHGs (IPCC 2013), which represent the relative radiative forcing of a GHG compared with CO_2, integrated over 100 years. When determining the GWP 100 indicator, the source of the characterisation factors used must be specified. The values published by the IPCC (2018b) are most helpful.

Although GHGs are an immediate and pressing concern, other pollutants and environmental degradation can also be included in indicators in order to identify and possibly avoid trade-offs, *e.g.* human health impacts caused by fine particles (Fantke *et al.* 2015), water stress (Boulay *et al.* 2018) and biodiversity damage potential (Chaudhary & Brooks 2018; Chaudhary *et al.* 2015). The Life Cycle Initiative, hosted by UN Environment, published two volumes of recommended life-cycle assessment indicators useful in this respect (Frischknecht & Jolliet 2016, 2019). This paper focuses on GHG emissions.

2.3.4 Unifying rules for quantifications, assessments and proof

Several standards and guidelines exist and are issued by various organisations (*e.g.* for buildings, see RICS 2017). Most of these standards and guidelines leave room for interpretation. That is why a basis for a unified approach is being developed in the context of standardisation activities (*e.g.* CEN/TC 350, ISO/TC 59 and ISO/SC 17) and ongoing research projects (*e.g.* IEA EBC Annex 72). Topics under discussion are: (1) the assessment of biogenic carbon in the supply chain of wood and other biomass; (2) the handling of biogenic carbon content in products; (3) the assessment of GHG emissions related to land use and (direct and indirect) land-use change; (4) the handling of the export of energy produced on-site, *e.g.* building-integrated photovoltaics; and (5) the handling of the recycling potential at the end-of-life stage of buildings. Decisions regarding the aspects mentioned have an influence the calculation of GHG emissions and thus on the reachability of (net-) zero-emission level of buildings.

2.3.5 Defining appropriate targets

In the past, targets were typically defined as a percentage reduction over an existing baseline, often limited by caveats involving technical and economic feasibility. However, this bottom-up approach does not adequately account for overall environmental limits, *e.g.* 'planetary boundaries', and the concept of a 'safe operating space' of 'spaceship earth' (Rockström *et al.* 2009; Steffen *et al.* 2015). A planetary boundaries approach derives science-based targets (Sabag Muñoz & Gladek 2017). With regard to climate change, the target is rather straightforward: net-zero CO_2 emissions need to be attained well before 2050 to comply with the 1.5°C target. This net-zero CO_2 emissions target may also require substantial extraction of CO_2 from the atmosphere or by the capture and storage of large amounts of biogenic CO_2. 'Climate neutral', '(net-) zero carbon' or '(net-) zero GHG-emission' buildings have the potential to be in line with the Paris Agreement.

Besides these technical questions on the calculation, modelling and assessment of life-cycle-based GHG emissions of buildings, terms and definitions should be carefully selected to show differences in the (net-) zero-emission approaches and to increase transparency and credibility. The next section proposes a system of terms and definitions.

3. A system of terms and definitions related to (net-) zero GHG-emission buildings

Various terms, definitions, modelling rules as well as options for balancing/compensation exist in the context of buildings. Several attempts have been made to provide an overview of zero-emission buildings and to describe latest developments. In contrast to net-zero energy systematic and comparative first systematic and analytical synopses on existing net-zero GHG-emission schemes and programmes for buildings are being published (*e.g.* EBC Building Energy Codes 2020). The World Green Building Council (WGBC) provides a list of the latest developments in several countries and organisations.[7] An assessment of national and international guidelines, standards and rules about the environmental assessment and GHG emissions of buildings is currently ongoing within the IEA EBC Annex 72 (Frischknecht 2018).

A typology of net-zero GHG-emission approaches for buildings is introduced below. This typology serves the purpose of grouping the different approaches and thus of enhancing transparency and facilitating understanding. It is suited for the assessment of operational or life-cycle-related GHG emissions.

3.1 A typology of approaches

The emission approaches are classified here into four categories: 'net-zero' (approaches A–C) and 'zero' (approach D):

A. Net-balance approach (with options Aa ('potentially avoided' emissions) and Ab (allocation)
B. Economic compensation
C. Technical reduction
D. Absolute zero.

Within approaches A–C, three additional variations are distinguished and used in the illustrative example (but not described in **Table 2**):

- full life-cycle
- operation only, direct and indirect emissions (on-site and supply chain)
- operation only, direct (on-site) emissions only.

The four approaches are now described.

3.1.1 Net-balance approach (approach A)

The 'net-balance' approach for the operational part or the full life-cycle includes two steps. In the first, the operational energy demand of the building as well as the energy produced on-site are determined. It should be specified which parts of the operational energy demand are included (items B6.1–B6.3, B7, B8) (**Figure 1**). In the case of a full life-cycle approach, the completeness of the building model should be stated (*e.g.* Frischknecht *et al.* 2019). The energy balance may be established on a yearly, monthly or even hourly basis. The scope of energy consumption as well as the granularity of the analysis will influence the share of self-consumption of energy produced on-site and to what extent the building produces more energy than it consumes during the use phase.

In a second step, the balance is assessed for which two options are available: either the potential benefits beyond the system boundary caused by exporting energy ('avoided GHG emissions') are attributed to the building (approach Aa 'potentially avoided emissions') and reported separately as additional information, or the pro rata share of GHG emissions caused by on-site energy production is attributed to the exported energy (approach Ab 'allocation') and no potential benefits beyond the system boundary are attributed to the building.

While a net-zero-emission building may be reached with approach Aa, it is not the case with approach Ab, unless it is combined with either approaches B or C. Approach Aa is problematic because it relies on the uncertain scenario that exported electricity avoids the average grid mix production of today. It also bears the real risk of double-counting of emission reductions with both the producer (the building) and the user (purchaser of exported energy). The amount of exported energy may be reported as additional information as requested by ISO 16475-1:2017 (Carbon metric of an existing building during use stage) (ISO 2017). In CEN/TC 350, experts are discussing whether and how the potential benefits and loads beyond the system boundary caused by exported energy could be reported in module D as additional information.

The main advantage of approach Aa is that net-zero-emission buildings are relatively easy to reach.

While some existing approaches assume the production of renewable energy on the building or the plot, other approaches allow the production of renewable energy (*e.g.* wind power) happening elsewhere. Marszal *et al.* (2010) provide an overview. Such approaches are in between net balance and economic compensation (see the next section).

3.1.2 Economic compensation (approach B)

The GHG emissions caused by construction, use and end of life of the building are determined. The resulting emissions are compensated (offset) in this approach by purchasing CO_2-emission certificates. It is possible to compensate also for the emissions of GHG other than CO_2 by such certificates. This approach offsets GHG emissions from buildings. However, it does not sufficiently contribute to the global net-zero GHG emission goal, because the building still emits

Table 2: System of terms, definitions and approaches for net-zero and zero-emission building during operation or full life-cycle.

Type	Net-zero-emission approaches				Zero-emission approach
	A		B	C	D
Name	**Net-balanced approach**		**Economic compensation**	**Technical reduction**	**Absolute zero**
Description	**Aa** Attributes the potential benefits caused by exported energy produced on-site solely to the GHG emissions of the building	**Ab** Attributes the pro rata share of GHG emissions caused by on-site energy production to the exported energy The amount of exported energy and potential benefits caused by exported energy are reported as additional information	Purchase of CO_2 certificates covering life-cycle GHG emissions caused by the building	Investment in technical-reduction measures to reduce life-cycle-based GHG emissions caused by the building	Use of construction materials and components with zero GHG emissions (including supply chain emissions), purchase of operational energy and water with zero GHG emissions (including supply chain emissions)
Feasibility	Net-zero GHG emissions are within reach by minimising the energy demand and maximising the generation of renewable energies and the inclusion of potentially avoided GHG emissions due to the export/sale of energy to third parties	Net-zero GHG emissions are within reach by minimising the energy demand and maximising the on-site production of energy with (building-integrated) renewable energies combined with an economic compensation (B) or a technical reduction (C)	Net-zero GHG emissions are within reach by purchasing CO_2 certificates/emission allowances and thus economically compensate for the remaining GHG emissions caused by the building[a]	Net-zero GHG emissions are within reach by purchasing technical GHG emission reductions to level off the GHG emissions caused by the building[b] The GHG emission reductions are achieved by one of the following negative-emission technologies (NET)[c] or carbon dioxide removal (CDR): · 'biological fixation'[d] · biogenic energy resources with carbon capture and storage (BECCS) · direct air capture with carbon separation and storage (DACCS)	Absolute zero emissions are within reach if all production processes, including all supply chains, are based on renewable energies and free from emissions of any GHG, and if no building products emitting CO_2 from carbonisation processes are used

(Contd.)

Type	Net-zero-emission approaches				Zero-emission approach
	A		B	C	D
Name	**Net-balanced approach**		**Economic compensation**	**Technical reduction**	**Absolute zero**
Limitations	Dependent on the (continuously declining) carbon intensity of avoided electricity producing technology or mix Avoided emissions attributed to the building need to be accounted for by the purchaser of exported energy. This measure to reach a net-zero GHG building leads to increased GHG emissions elsewhere Double-counting of low-carbon energy production is likely to occur	Net-zero GHG-emission buildings are reachable only with financial compensation or technical reduction	Financial compensation does not sufficiently contribute to the global net-zero emission target The cheapest reduction potentials are likely located in emerging and developing economies. These countries may thus face high costs in future when it is their turn to reduce GHG emissions	Achievable if permanent carbon storage is technically and economically feasible	Very difficult to achieve due to the current dependence on certain materials (float glass, cement, *etc.*). A viable carbon capture and storage is needed to reduce emissions from the production of these materials

Notes: GHG = greenhouse gas.

[a] The GHG emissions to be compensated economically equal the GHG emissions caused in construction, use and end of life of the building under assessment. Ideally, a safety factor (*e.g.* 1.05 or 1.10) is included.

[b] The GHG emissions to be captured and fixed/stored long term equal the GHG emissions caused in construction, use and end of life of the building under assessment. Ideally, a safety factor (*e.g.* 1.05 or 1.10) is included.

[c] For NET, see, for example, Minx *et al.* (2018).

[d] Extraction of ambient CO_2 through photosynthesis and long-term storage in biomass (living or dead; increase of natural sinks): achievable with afforestation, improved forest management; the storage of carbon in long-living buildings and wood products; the storage of carbon in the soil; and long-term underground storage of biogenic carbon.

GHGs (for which emission certificates are purchased). Emission certificates may have been issued for a *non-increase* in GHG emissions (certificates for CO_2 not emitted due to investments in wind power plants avoiding investments in new coal power plants). If a certificate is issued for a real emission reduction, then CO_2 is still being emitted, namely those amounts for which emission certificates are purchased. On a global level, a maximum of 50% of GHG emissions can be reduced by CO_2 certificates: per 1 tonne emission reduction for which a certificate is issued, 1 tonne is still being emitted (by the entity purchasing the certificate).

The advantage of approach B is its rather straightforward implementation, given a sufficient amount of reliable and trustworthy emissions certificates available. The main disadvantage is the fact that net-zero CO_2 emissions will not be reached with economic compensation only.

The framework issued by the UK Green Building Council (UK GBC 2019) recommends emission offsetting.

3.1.3 Technical reduction (approach C)

The GHG emissions caused by construction, use and end of life of the building are determined. Investments are made in technical-reduction measures to extract the equivalent amount of CO_2 emissions from the atmosphere. Technical-reduction measures include negative-emission technologies (NET) such as 'biological fixation' (*e.g.* by afforestation), biogenic energy resources with carbon capture and storage (BECCS), or direct air capture[8] with carbon separation and storage (DACCS). This approach allows one to reach net-zero-emission buildings and contributes at the same time to the global net-zero-emission goal.

The main advantage of this solution is a real and technical reduction of the concentration of CO_2 in the atmosphere. Its main disadvantage is, however, that many issues surrounding these technologies are unresolved: if, when, at what costs and at which risks (of CO_2 leakage or even release) such options will be available and their long-term viability. A further unknown dimension is the geopolitical aspects surrounding the deployment of such technologies and the sharing of long-term costs, responsibilities and liabilities.

3.1.4 Absolute zero (approach D)

The building is made of construction materials with zero-emission supply chains and end-of-life management, and using zero GHG-emission fuel and electricity in construction and use. Although (currently) not within reach, this approach would allow for real zero GHG-emission buildings and would at the same time contribute to the global net-zero GHG-emission goal.

While absolute zero on-site GHG emissions may be within reach during the operation of buildings, this is much less the case for the supply chains of operational energy demand and the supply chains of construction materials and building elements.

All approaches described may entail additional costs. This may benefit the economically privileged and penalise the disadvantaged (Klinsky & Mavrogianni 2020). However, the future climate costs of not acting now surpass by far the costs of GHG-reduction measures today (Stern 2006).

The typology summarised in **Table 2** is intended to serve the following purposes:

- Increase the transparency, understanding and reliability in the discussion about climate-neutral buildings.
- Identify the common aspects and differences between existing and emerging approaches and concepts.
- Classify the existing and emerging approaches.
- Assist in the discussions about national strategies on the calculation and assessment rules for climate-neutral buildings.

The typology presented in **Table 2** may be further detailed, in particular regarding the net-zero-emission approaches, for instance, by defining a physical perimeter within which compensation or balancing should take place (within the borders of the plot, within the district, within the country, *etc.*).

3.2 Proposed terms for (net-) zero-emission building approaches

Approaches A–D characterised in section 3.1 and **Table 2** can be applied on (partial) life-cycle-based GHG emissions. The proposed terms to distinguish these options are provided in **Table 3**.

It is advisable to communicate the applicable scope of the assessment that underlies the net-zero GHG-emission approach as in some cases it might only cover the *in situ* emissions during the use phase of a building, whereas other approaches cover the full life-cycle.

The approaches and terms proposed may be combined in cases where the building assessment is, for example, including the potential benefits beyond the system boundary and the remaining emissions are economically compensated using CO_2 certificates/allowances ('net-zero-emission building by credits from emissions avoided elsewhere and economic compensation').

3.3 Illustrative case study

The four different approaches are illustrated using fictive (but realistic) numbers. The three different variations regarding the scope of the assessment are added to approaches A–C.

The illustrative building causes 10 kg CO_2-eq/m^2 and /year embodied GHG emissions (**Table 4**). The manufacture of the photovoltaic (PV) system mounted on the building causes 2 kg CO_2-eq/m^2 and /year. The operation of the building causes 3 kg CO_2-eq/m^2 and /year direct emissions and 1 kg CO_2-eq/m^2 and /year indirect (supply chain) emissions. The share of exported electricity is 30%, *i.e.* 70% of the electricity produced with PV is self-consumed in the building. The emission intensity of the grid mix is 500 g CO_2-eq/kWh and of PV electricity 50 g CO_2-eq/kWh.

Figure 3 shows the GHG emissions (above the *x*-axis) and the GHG-emission reductions (below the *x*-axis) separately. The potentially avoided GHG emissions caused by exported electricity (variations 1–3 in approach Aa) are fixed. Thus, it depends on the scope of the assessment whether or not net-zero GHG emissions are achieved (Aa2) or even surpassed (Aa3). Approach Ab does not include any potentially avoided emissions and net-zero GHG-emission buildings are out of reach. In approaches B and C, the amount of emission reductions is determined by the amount of GHG emissions, and thus by the definition of the scope. In approach D, no GHG are emitted and thus no GHG emission reductions are required. Approach D is hardly reachable today because GHG emissions are likely to occur in the supply chains of electricity, renewable fuels and construction materials.

3.4 Communication to third parties

The specification of targets for limiting, avoiding or compensating for GHG emissions in the life-cycle of buildings practically corresponds to a benchmark, in the sense of a limit or target value. A robust approach requires clear communication with users of the background, calculation and verification methods as well as the databases (sources and detailed information).

The structure of information to describe a benchmark is part of a new standard ISO 21678 (2020). However, the authors propose to specify the approach used when defining (net-) zero GHG-emission targets.

4. Conclusions and outlook

Claims about climate-neutral buildings based on a (net-) zero GHG-emission approach are expected to become the subject of sustainability reporting, the basis for new contracting models and part of voluntary commitments. The issues discussed in this paper will play a role in formulating future legal requirements to limit GHG emissions from buildings.[9]

Table 3: Proposal for specific terms in the context of (net-) zero greenhouse gas (GHG)-emission buildings.

Name	Variations in scope				Explanation
	Operational on-site GHG emissions	**Operational including supply chain GHG emissions**	**Embodied GHG emissions**	**Life-cycle-based GHG emissions**	
Zero × GHG emissions building	■	■	■	■	Absolute zero (Option D)
Net zero × GHG emissions building by economic compensation	■	■	■	■	Combined with economic compensation (Option B)
Net zero × GHG emissions building by technical reduction	■	■	■	■	Combined with technical reduction (Option C)
Net zero × GHG emissions building by credits from emissions avoided elsewhere	■	■	■	■	Including potential benefits beyond the system boundary (Option Aa)

Note: '×' = Different variations of scopes: 'operational on-site', 'operational including supply chains', 'embodied' or 'life-cycle based'. The appropriate term can be applied in each circumstance.

Table 4: Key figures for the virtual building illustrating the (net-) zero greenhouse gas (GHG) emission approaches and variations.

		Unit	Value
Construction		kg CO_2/m^{2}a	10
PV system		kg CO_2/m^{2}a	2
Operation	On-site	kg CO_2/m^{2}a	3
	Supply chain	kg CO_2/m^{2}a	1
Exported PV electricity		Share	30%
Electricity mix		kg/kWh	0.5
PV electricity		kg/kWh	0.05

Note: PV = photovoltaic.

Figure 3: Greenhouse gas (GHG) emissions and GHG emission reductions of the fictive building according to the four approaches and three variations.

Note: A = net balance; B = economic compensation; C = technical reduction; D = absolute zero; a = potentially avoided emissions; b = allocation; 1 = life-cycle based; 2 = direct and indirect operational emissions; and 3 = direct (on-site) emissions.

The need exists to generate and agree upon a clear set of explanations, definitions and basic assumptions related to the terms used in policy-making, communication and marketing to re-establish and ensure and maintain acceptance, trust and credibility, including the following:

- The variety of (net-) zero-emission approaches characterised in this paper show different levels of ambition and effectiveness in terms of the contribution to the fulfilment of the Paris Agreement.
- The typology considered useful in the communication of (net-) zero GHG-emissions building concepts and policies launched by companies and public administration.
- A uniform, robust system is needed for the variety of terms, definitions, system boundaries involving (net-) zero GHG-emission concepts for the built environment. Science and international standardisation can make significant contributions in this direction. The relevant actors should be involved in the process of coordination and harmonisation.
- The future terms, definitions and system boundaries within the framework of legally binding requirements must be clear, unambiguous and provide legal certainty. The level of ambition should be raised the course of time.
- Comprehensive (*i.e.* life-cycle-based) (net-) zero-emission building targets are needed by 2025, if 2050 emission targets are to be achieved.

The development and application of transparent, comprehensible and science-based terms, definitions, system boundaries, calculation and verification rules is a prerequisite not only for the credibility of institutions of all kinds but also for achieving the global goals in the field of climate protection. The international project IEA EBC Annex 72 is currently working on this and similar topics. The publication of its results is expected in early 2023.

Notes

1 Abbreviations such as nZEB may be misleading or misunderstood because the 'n' could be interpreted as 'net' or 'nearly'.

2 ISO TC 59 is the International Standards Organization technical committee on 'Buildings and Civil Engineering Works'. ISO SC 17 is the scientific committee on 'Sustainability in Buildings and Civil Engineering Works'. See: https://www.iso.org/committee/322621.html.

3 European Committee for Standardization (CEN) technical committee 350 on 'Sustainability of Construction Works'. See: https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:481830&cs=181BD0E0E925FA84EC4B8BCCC284577F8.

[4] International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 57 'Evaluation of Embodied Energy and CO_2e for Building Construction'. See: http://www.annex57.org/.
[5] IEA EBC Annex 72 'Assessing Life Cycle Related Environmental Impacts Caused by Buildings'. See: https://annex72.iea-ebc.org/.
[6] Details on operational aspects are included in an international standard (ISO 2017).
[7] See https://www.worldgbc.org/advancing-net-zero/what-net-zero (accessed on August 31, 2020).
[8] For instance, practiced by companies such as climeworks (https://climeworks.com/) (accessed on August 31, 2020).
[9] Some requirements were also stipulated in the Graz Declaration for Climate Protection in the Built Environment (TU Graz 2019).

Acknowledgements
The authors thank the experts in ISO/TC 59/SC 17, CEN/TC 350, IEA EBC projects Annex 57 and Annex 72, and in national harmonisation and consensus-finding processes for the inputs received during discussions and debates. They also thank the anonymous reviewers for their valuable comments and recommendations. The authors also thank Richard Lorch for his kind support during the preparation and finalisation of the contribution.

Competing interests
The authors have no competing interests to declare.

Funding
The paper was prepared with funding support from the Federal Ministry of Economic Affairs and Energy (BMWi) in Germany, coordinated by the project management agency PTJ (project number 03ET1550A) and the Swiss Federal Office of Energy (grant number SI/501549-01).

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How to cite this article: Lützkendorf, T., & Frischknecht, R. (2020). (Net-) zero-emission buildings: a typology of terms and definitions. *Buildings and Cities*, 1(1), pp. 662–675. DOI: https://doi.org/10.5334/bc.66

Submitted: 07 July 2020 **Accepted:** 03 September 2020 **Published:** 25 September 2020

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