I Positive Energy Buildings e Districts oltre il paradigma NZEB: verso un approccio *whole-life*

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Abstract. Il presente contributo è riferito all'ambito di ricerca e applicazione dei Positive Energy Buildings (PEBs) e Districts (PEDs) e intende esplorare lo stato dell'arte nell' uso delle analisi LCA in materia di impatti energetici e emissioni di CO_{2eq}. Con l'obiettivo di comprendere l'evoluzione del dibattito su PEBs e PEDs e il loro recepimento e attuazione, viene effettuata un'analisi della letteratura scientifica, di programmi, standard e normative esistenti. Tale analisi intende contribuire a una migliore definizione del perimetro di applicabilità e di valutazione dei PEBs/PEDs, utilizzando la lente del *Life Cycle Assessment*, da estendere oltre la sola fase di uso. Lo studio permette altresì di evidenziare i principali *gap* e gli aspetti da incentivare per favorirne la diffusione.

Parole chiave: *Positive energy buildings*; *Positive energy districts*; *Regenerative architecture*; *Net-positive architecture*; *Life Cycle Assessment*.

Introduzione

Il contesto ambientale e il paradigma rigenerativo

Il Regenerative – o *Net-positive* – design rappresenta lo step successivo al paradigma *Net Zero*: una evoluzione del concetto di sostenibilità che non mira alla sola riduzione degli impatti ambientali, ma a produrre benefici per i sistemi sociali, tecnici ed ecologici (Mang and Reed, 2012).

La definizione di Positive design estende, quindi, l'analisi del bilancio degli impatti all'intero ciclo di vita del prodotto e, potenzialmente, agli eventuali impatti pre-sviluppo (Cole and Fedoruk, 2014).

L'energia necessaria durante il ciclo di vita di un manufatto comprende la *Lifecycle Embodied Energy* (LCEE) e la *Operational Energy* (OE). Analogo discorso riguarda le emissioni di CO_2 (o CO_{2eq}). L'EE è generalmente inferiore alla OE, e pertanto viene spesso trascurata; con l'emergere dell'attenzione verso gli NZEBs – *Net Zero Energy Buildings* assume una maggiore rilevanza, rappresentando fino a circa il 46% degli impatti energetici (Dixit, 2017).

Sebbene il paradigma rigenerativo riguardi ambiti che vanno oltre la valutazione energetica e delle emissioni di CO_2 (consumo d'acqua, emissioni di inquinanti, impatti sociali, economici, etc.), il presente contributo si concentra sul tema dei Positive Energy Buildings (PEBs) e Districts (PEDs) e intende esplorare lo stato dell'arte nell'applicazione delle analisi LCA – *Life Cycle Assessment* in materia di impatti energetici e emissioni di CO_{2eq}. Tale approfondimento vuole contribuire a una definizione di PEBs e PEDs che vada oltre la sola fase d'uso del manufatto, oggi assente, estendendo l'analisi del bilancio degli impatti all'intero ciclo di vita. Il contributo intende, inoltre, individuare i *gap* e gli ostacoli che ne limitano la diffusione.

Da Net Zero a Positive Energy Buildings

La maggior parte della letteratura su (Net)PEBs, convenzionalmente descritti come edifici che producono più energia di quella che consumano, li colloca in analogia agli NZEBs e li considera guidati dai medesimi principi. Sebbene NZEBs e NPEBs condividano molte caratteristiche, esistono molteplici differenze tra loro: all'interno della rete di scambio di energia, il periodo di riferimento del bilancio, la valutazione sistemica della performance, il comportamento dell'utente e l'impatto ambientale della produzione energetica (Cole and Fedoruk, 2014).

Pertanto, una analogia tra NZEBs e NPEBs non pare pienamente accurata.

In Europa, i concetti di *Nearly* e Net ZEB sono stati definiti all'interno dell'*Energy Performance of Buildings Directive* (EPBD). Il Parlamento Europeo ha richiesto che dal 2020 tutti i nuovi edifici si conformino a tali standard; l'esatta definizio-

Positive Energy Buildings and Districts beyond the NZEB paradigm: towards a whole-life approach

Abstract. This paper focuses on the research topic and application of Positive Energy Buildings (PEBs) and Districts (PEDs), and explores the state-of-the-art in the use of LCA analyses on energy impact and CO_{2eq} emissions. An analysis of the scientific literature and existing programmes, standards and regulations is carried out to understand the evolution of the debate on PEBs and PEDs and their implementation. This analysis allows to better define the scope of applicability and assessment of PEBs/PEDs through the lens of the Life Cycle Assessment to extend its definition beyond the sole usage phase. The study also highlights the main gaps and the aspects to be encouraged to promote their diffusion.

Keywords: Positive energy buildings; Positive energy districts; Regenerative architecture; Net-positive architecture; Life Cycle Assessment.

Introduction

The environmental context and the regenerative paradigm

Regenerative – or Net-positive – design is the next step to the Net Zero paradigm, an evolution of the concept of sustainability that, instead of aiming at reducing environmental impacts, seeks to produce benefits for social, technical and ecological systems (Mang and Reed, 2012).

The definition of Positive design, therefore, extends the analysis of the balance of impact to the entire product lifecycle and, potentially, to any pre-development impacts (Cole and Fedoruk, 2014).

The energy required in the entire lifecycle of a product includes the Lifecycle Embodied Energy – LCEE and the Operational Energy – OE. The same applies to CO_2 emissions (or CO_{2eq}). EE is generally lower than OE, but with the emergence of NZEBs – Net Zero Energy Buildings, it assumes greater relevance, accounting for up to about 46% of energy impacts on the lifecycle (Dixit, 2017).

Although the regenerative paradigm concerns issues that go beyond energy assessment and CO_2 emissions (water consumption, emissions of pollutants, social and economic impacts, etc.), this paper focuses on Positive Energy Buildings (PEBs) and Districts (PEDs) to explore the state-of-the-art in applying LCA analysis on energy impacts and CO_{2eq} emissions.

This in-depth study contributes to a definition of PEBs and PEDs that goes beyond the usage phase of the building, which is currently missing, extending the analysis of the impact balance to the entire lifecycle. It also identifies the gaps and obstacles that limit their diffusion.

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ne dei termini viene poi delegata agli Stati Membri (European Commission, 2010).
I termini PEBs o PEDs, invece, non sono stati ancora definiti dalla normativa UE (Tuerk *et al.,* 2021), sebbene numerose definizioni, non sempre convergenti, esistano in letteratura e alcuni Stati abbiano individuato obiettivi che vanno oltre i requisiti NZEB (es., PEBs in Danimarca e Francia, climate neutral new buildings in Germania e zero carbon standards nell'UK) (D'Agostino and Zangheri, 2016). Esistono, tuttavia, indicazioni che presumono l'introduzione di linee guida e obiettivi per la prossima stesura della EPBD nel 2026 (Magrini *et al.,* 2020).

Gaps di ricerca e barriere applicative
Vengono rilevati numerosi limiti allo sviluppo di PEBs e PEDs che richiedono approfondimenti della ricerca, delle metodologie di valutazione, delle prassi progettuali, costruttive e di utilizzo, nonchè la trasformazione del contesto normativo, tecnologico-infrastrutturale e socio-economico (Tab. 1).

Metodologia di ricerca

La literature review e il Lifecycle approach
Con l'obiettivo di comprendere l'evoluzione del dibattito su PEBs e PEDs e il loro recepimento e attuazione, viene effettuata una analisi della letteratura scientifica e di programmi, standard e normative esistenti (Fig. 1).
Una prima ricerca ha condotto alla selezione di oltre 60 articoli su PEBs e PEDs; su 40 dei quali viene effettuata una analisi comparativa.
Per quanto riguarda programmi, standards e normative, dopo un'indagine su riviste scientifiche di settore, ne è seguita una specifica per ogni stato membro dell'UE, luogo in cui PEBs e PEDs risultano maggiormente discussi (Hawila *et al.,* 2022).
Sia per l'analisi della letteratura che di programmi, standard e normative, una parte degli articoli analizzati viene scartata in quanto non esplicitamente riferita al paradigma *Net-positive* (es., *Net Zero*) o carente di approfondimento su aspetti *energy-positive*; vengono inoltre tralasciati studi relativi a singole tecnologie o semplici simulazioni di calcolo.
Dai riferimenti analizzati vengono evidenziati i temi centrali riguardanti l'analisi del ciclo di vita (LCA), gli elementi di convergenza e divergenza.

Risultati

Literature review
Per ciascuna fonte analizzata vengono raccolte informazioni ritenute rilevanti per una migliore descrizione dei PEBs e PEDs e dello stato dell'arte del dibattito scientifico sul paradigma *energy-positive* (Fig. 2).
L'analisi degli argomenti trattati suggerisce come, se le ricerche su PEBs e PEDs ne approfondiscono la comprensione, le esperienze di applicazione di tali principi, specialmente secondo un approccio LCA, risultino rare.
Successivamente vengono analizzati i perimetri di valutazione come definiti nei rispettivi articoli (Fig. 3), che delimitano la metodologia di calcolo e i confini del sistema. Questi risultano molteplici, sebbene si riconosca una prevalenza di analisi riguardanti edifici nuovi e riqualificati, il cui bilancio energetico viene valutato in fase operativa su base annuale, comprendendo consumi e produzioni in situ per usi finali (es., Heating, Ventilation and Air Conditioning, Domestic Hot Water, Lighting, Plug load/Appliances).

From Net Zero to Positive Energy Buildings
Most literature on (Net)PEBs, conventionally described as buildings that produce more energy than they consume, place them in analogy to NZEBs and consider them guided by the same principles. Although NZEBs and NPEBs share many characteristics, there are many differences between them, precisely within the energy trading network, the calculation period, the systemic assessment of performance, user behaviour and the environmental impact of energy production (Cole and Fedoruk, 2014). Therefore, an analogy between NZEBs and NPEBs is not fully accurate.
In Europe, the concepts of Nearly and Net ZEB have been defined within the Energy Performance of Buildings Directive (EPBD). The European Parliament has required all new buildings to comply with these standards from 2020; the exact definition of the terms is delegated to the Member States (European Commission, 2010).
On the other hand, the terms PEBs or PEDs have yet to be defined by EU legislation (Tuerk A. *et al.,* 2021), although numerous definitions, not always convergent, exist in the literature, and some States have identified objectives beyond the NZEB requirements (e.g., PEBs in Denmark and France, climate-neutral new buildings in Germany, and zero carbon standards in the UK) (D'Agostino and Zangheri, 2016). However, indications assume the introduction of guidelines and targets for the next draft of the EPBD in 2026 (Magrini *et al.,* 2020).

Research gaps and application barriers
There are several limitations to developing PEBs and PEDs. These gaps concern the need for in-depth research, evaluation methodologies, design, construction and use practices, and the transformation of the regulatory, technological-infrastructural and socio-economic context (Tab. 1).

Research methodology
The literature review and the Lifecycle approach
An analysis of the scientific literature and existing programmes, standards and regulations is carried out to understand the evolution of the debate on PEBs and PEDs and their application (Fig. 1).
An initial search led to the selection of over 60 articles on PEBs and PEDs, and a comparative analysis was carried out on 40 of them.
Regarding programmes, standards, and regulations, after a general search in scientific journals of the sector, a specific investigation was carried out for each EU member state, as Europe is the place where PEBs and PEDs are most discussed (Hawila *et al.,* 2022).
Both for the literature analysis and for that of programmes, standards and regulations, part of the articles studied are discarded as they either do not explicitly refer to the Net-positive paradigm (e.g., Net Zero) or they lack in-depth analysis on energy-positive aspects, studies relating to single technologies or simple calculation simulations.
The references considered highlight the issues of debate concerning the lifecycle analysis (LCA), as well as the elements of convergence and divergence.

Results
Literature review
For each reference, the relevant information is collected to allow a better de-

Tab. 01

Tab. 01 |

MAIN BARRIERS
RESEARCH:
• Lack of studies that provide a holistic/broad PEB definition framework. (Ala-Juusela, M.; Rehman, H.u.; Hukkalainen, M.; Reda, F., 2021)
• Lack of research on LCA and LCC for PEBs. (Kumar, G.M.S.; Cao, S., 2021)
• Lack of understanding of contributions in the energy balance and RE production. (Hawila A. A. W. *et al.*, 2022)
• Lack of understanding of the role of energy communities and PEB/PED for decarbonization, and
• Lack of access to real-time data or generation capacity and spatial limitations. (Tuerk A. *et al.*, 2021)
• Need for testing performance in use by monitoring energy use and system performance. (Jones P. *et al.*, 2020)
ASSESSMENT:
• Need for a comprehensive framework of evaluation (physical boundaries, balance contributions, main metrics, balancing period, and amount of surplus energy). (Hawila A. A. W. *et al.*, 2022)
• Need for targets and threshold limits. (Ala-Juusela M. *et al.*, 2016)
• Lack of a common approach for carbon emissions calculations (e.g., the three-scope emission classification). Demand for a quantitative (universal) definition for objectively evaluating PEDs. (Albert-Seifried V. *et al.*, 2021)
• Lack of insight into the performance during the year on a monthly, weekly and daily basis. (Ala-Juusela, M.; Rehman, H.u.; Hukkalainen, M.; Reda, F. 2021)
• Demand for a more “dynamic” view of the building (e.g., generation–consumption matching), and
• Inaccurate weather data (present and future) and influence of weather conditions. (Kolokotsa D. *et al.*, 2011)
• Lack of focus on lowering the building energy need and increasing on-site generation systems efficiencies, and
• Lack of building performance quality. (Heiselberg, P. K. (Ed.) 2016)
• Lack of analysis of load matching and grid interaction. (Voss K. *et al.*, 2012)
• Overestimation of the techno-economic performance. (Kumar, G.M.S.; Cao, S. 2021)
• Restriction of the scope of analysis to building-connected energy demand in PED energy performance. (Karen Williams *et al.*, 2022)
DESIGN, CONSTRUCTION AND USE:
• Lack of integrated planning. (Boll J. R. *et al* 2021)
• Lack of analysis of technological approaches and urban contexts. (Hedman A. *et al.*, 2021)
• Need of integrators and service providers, and
• Lack of competences and skills needed for realizing the integrated service with product’s pricing. (Ala-Juusela M., Tuerk A., 2022)
• Need for construction industry experience; vocational training and capacity building. (Kumar, G.M.S.; Cao, S. 2021)
• The unpredictability of user action. (Kolokotsa D. *et al.*, 2011)
GOVERNANCE AND REGULATION:
• Need for a clear PED definition and boundaries. (Karen Williams *et al.*, 2022)
• Current immaturity and unpredictability of the regulations in the EU. (Ala-Juusela M., Tuerk A., 2022)
• Need for integration of EU regulatory approach for RE and common indoor environment requirements in buildings in the EU and at the district level. (Boll J. R., *et al.*, 2021)
• Need for standardization in the EU energy community (and self-consumption) provisions. (Tuerk A. *et al.*, 2021)
• Lack of governmental and institutional support, and standards. (Takva C., Caliskan B. C., Cakici F., Z., 2022)
• Lack of policymakers’ awareness of inertia to changes. (Uspenskaia, D. *et al.*, 2021)
INFRASTRUCTURE AND TECHNOLOGY:
• Inadequacy of infrastructure. (Takva C., Caliskan B. C., Cakici F. Z., 2022)
• Need for higher energy-efficient buildings, use RE sources, cascading local energy flows by making use of any surpluses, and
• Need for smarter controls to match demand and supply, minimize the liability on the grid and maximize the effectiveness of PED. (Hedman A. *et al.*, 2021)
• Need to optimize the energy system at a district level. (Karen Williams *et al.*, 2022)
• Overload of networks due to surplus electricity production with low national demand and lack of storage, and
• Interaction between new buildings and existing building stock. [Technical energy and urban integration] (Ala-Juusela M. *et al.*, 2016)
• Atypical availability of renewable energy. (Kolokotsa D. *et al.*, 2011)
SOCIAL AND ECONOMICAL DIMENSION:
• Lack of customer, user, and politicians’ awareness. (Heiselberg, P. K. (Ed.) 2016)
• Economic viability. (Uspenskaia, D. *et al.*, 2021)
• Social and cultural resistance to initial costs. (Kumar, G.M.S.; Cao, S. 2021)
• Social (stakeholder and citizen engagement), and
• Market (funding, markets, and business models). (Krangsås, S.G. *et al.*, 2021)

scription of PEBs and PEDs and to favour a definition of the in-depth state of the energy-positive paradigm (Fig. 2).
The analysis of the topics covered suggests that, while the research on PEBs and PEDs deepens their understanding, experiences concerning implementation of these principles, especially according to an LCA approach, are rare.
Subsequently, the scope of assessment defined in the respective articles is analysed (Fig. 3), delimiting the calculation methodology and the boundaries of the system. The assessment boundary used by the various studies is manifold. However, a prevalence of analyses concerning new and refurbished buildings is recognised, whose energy balance is evaluated in the operational phase on an annual basis, including on-site consumption and production for the following final uses: Heating, Ventilation and Air Conditioning, Domestic Hot Water, Lighting, Plug loads/Appliances.

Programmes, Standards and Regulations

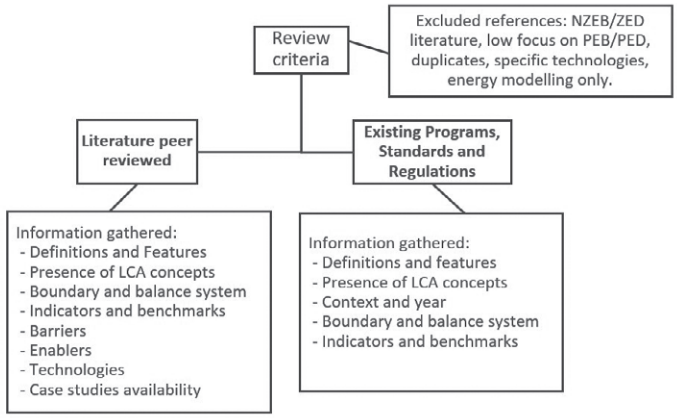
The research provided an overview of ongoing experiences by collecting existing programmes and standards (Tab 2).
As anticipated, Europe is the geographical area where PEBs and PEDs are most discussed, particularly in the

01 | Schema sulla metodologia di ricerca
Outline on research methodology

02 | Contenuto degli articoli
Article's content

03 | Perimetro di valutazione negli articoli analizzati. * Se non specificato inclusi in questo gruppo. **Alcuni studi utilizzavano vari perimetri. A=Any; N=New; R=Retrofit; O=Operational; W=Whole-Life; Y=Year; ON=On-site; All=HVAC, DHW, Lighting, Plug load/Appliances
*Scope of assessment in the analysed articles * Included in this group if not specified. ** Some studies used various scopes. A=Any; N=New; R=Retrofit; O=Operational; W=Whole-Life; Y=Year; ON=On-site; All=HVAC, DHW, Lighting, Plug load/Appliances*

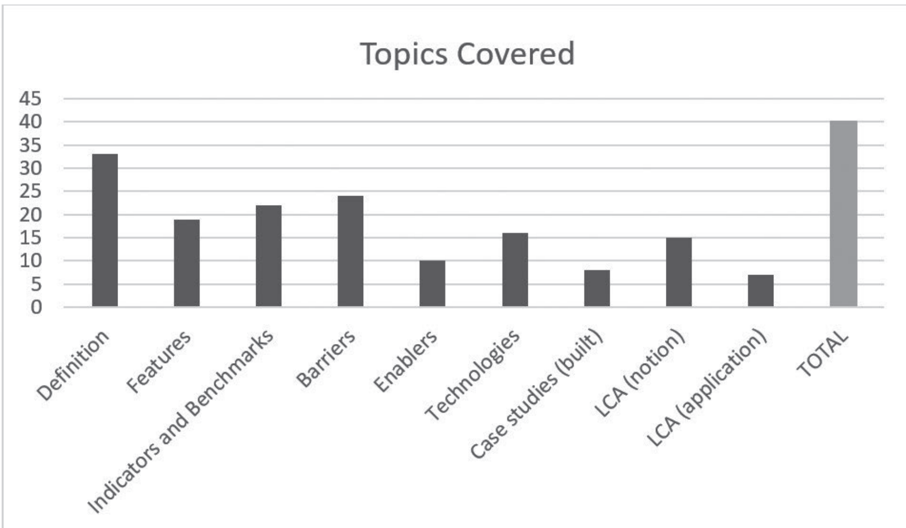
| 01



Programmi, Standards e Quadro Normativo
La ricerca ha consentito di costruire un quadro sulle esperienze in atto, attraverso la raccolta di programmi e standard esistenti (Tab 2).
Come anticipato, l'Europa risulta l'area geografica in cui PEBs e PEDs vengono maggiormente discussi, in particolare nell'ambito dei PED Programme (SET)-Plan Action 3.2 e Horizon 2020 Framework Programme – Smart Cities and Communities. Ulteriori iniziative a livello nazionale si ritrovano in Austria, Germania e Francia.
Contestualmente, vengono individuati standard nazionali e internazionali, con l'obiettivo di certificare progetti *energy positive*.

Mentre dal 2009 gli standard NZEB iniziano a far parte del quadro normativo degli Stati, ad oggi, non vengono reperite normative nazionali che vincolino la costruzione a standard PEBs e PEDs. La normativa Francese RE2020 (MTE, 2020), per esempio, più volte indicata in letteratura in quanto impone standard *Net-positive*, non pare riportare tali obblighi.
Menzioni rispetto PEBs e PEDs vengono rilevate nei *National Energy and Climate Plans* di Austria, Belgio, Francia e Lussemburgo (European Commission). Infine, ulteriori definizioni Net-positive vengono evidenziate in Svizzera (Hermelink A. *et al.*, 2012).

| 02



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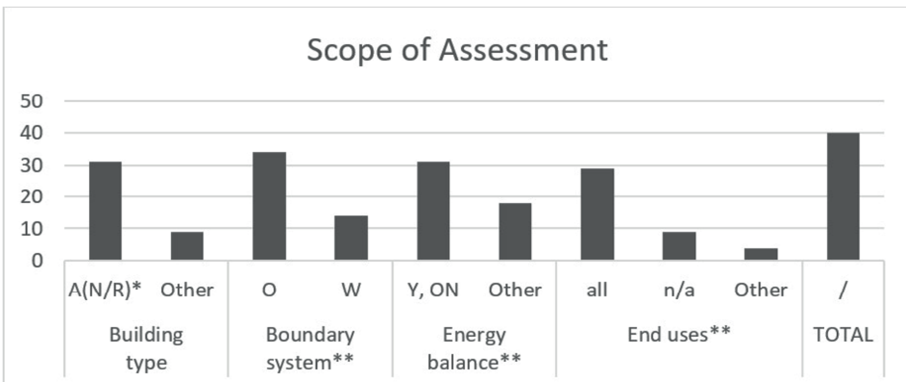


Tab. 02 | * Lifecycle cost. A=Any; RE=Residential; AD=Administrative; OF=Office; ED=Education; N=New; R=Retrofit; O=Operational; W=Whole-Life; Y=Year; M=Month; W=Week; D=Day; ON=On-site; OFF=Off-site; All=HVAC, DHW, Lighting, Plug load/Appliances

Tab. 02 |

Programs	**Building type**	**Boundary System**	**Energy Balance**	**End Uses**
Atelier, 2019, EU	A (N/R)	O, /	M/Y, ON/OFF	all
COST Action PED-EUNET, 2020, EU	A (N/R)	O, /	Y, ON/OFF	n/a
Cultural-E, 2019, EU	A (N/R)	O, /	Y, ON	all
EEPOS, 2012, EU	A (N/R)	O, /	Y, ON	n/a
EXCESS, 2019, EU	A (N/R)	O, /	Y, ON	n/a
Making-city, 2018, EU	A (N/R)	O, /	Y, ON	n/a
Pocityf, 2019, EU	A (R)	O, /	Y, ON	n/a
PED Programme, (SET)-Plan, Act. 3.2, 2015, EU	A (N/R)	O, /	Y, ON	n/a
SPARCS, 2019, EU	A (N/R)	O, /	Y, ON	n/a
Syn.ikia, n/a, EU	A (N)	O, /	Y, ON	n/a
+CityXChange, 2018, EU	A (N/R)	O, /	Y, ON	all
Plusenergiehaus, 2008, AT	A (N/R)	O, /	Y, ON	n/a
Zukunftsquartier (City of tomorrow), 2019, AT	A (N/R)	W, 40Y*	Y, ON	n/a
Effizienzhaus Plus, 2011, DE	A (N/R)	O, /	Y, ON	all
COMEPOS, 2013, FR	RE (N/R)	O, /	Y/M/W/D, ON	n/a
Standard / Rating system				
Living Building Challenge – LBC, 2019, INTL	A (N/R)	W, n/a	Y, ON	n/a
Passivehouse standard Premium, 2015, INTL	RE, AD (N/R)	O, /	Y, n/a	all
Bepos+ Effinergie, 2017, FR	A (N)	O, 50Y	Y, ON	all
E+C- (Bâtiment à Énergie Positive & Réduction Carbone, lev. 4), 2016, FR	A (N)	W, 50Y	Y, ON	n/a
Climate Positive award, n/a, DE	A (N/R)	O, /	Y, ON	all
Powerhouse Paris Proof, 2019, NO	OF, ED, (N/R)	W, 60Y	Y, ON	All, plug load excluded
Minergie A, 2011, CH	A (N/R)	W, n/a	Y, ON	Building related and auxiliary

Lifecycle PEBs e PEDs in letteratura

Il confronto tra il perimetro di valutazione descritto in articoli, programmi e standard non esprime un quadro pienamente sovrapponibile. Risultano maggiori sovrapposizioni tra articoli e programmi, sebbene raramente questi ultimi facciano esplicito riferimento agli usi finali considerati nel bilancio. Gli standard analizzati, invece, utilizzano un perimetro piu' incentrato su un approccio *whole-life* e sull'analisi di specifiche tipologie di edifici (Fig. 5). Tuttavia, il *boundary system* risulta poco trasparente o standardizzato.

Le valutazioni sul ciclo di vita vengono spesso riferite al *Lifecycle Cost*, nonostante una parte consistente di fonti ne riconosca l'importanza anche dal punto di vista energetico.

Dal quadro di insieme, riferito ad articoli e standard, è possibile

context of the PED Programme (SET)-Plan Action 3.2, and Horizon 2020 Framework Programme – Smart Cities and Communities. Further initiatives at a national level can be found in Austria, Germany, and France.

At the same time, nationally and internationally recognised standards are identified to certify energy-positive projects.

While the NZEB standards have become part of the regulatory framework of the States since 2009, to date, no national regulations have been found that oblige construction according to PEBs and PEDs standards. The French RE2020 regulation (MTE, 2020), for example, repeatedly indicated in the literature as imposing Net-positive standards, does not appear to include such obligations.

PEBs and PEDs are mentioned in the *National Energy and Climate Plans* of Austria, Belgium, France, and Luxembourg (European Commission). Finally, further Net-positive definitions are highlighted in Switzerland (Hermelink *et al.,* 2012).

Lifecycle PEBs and PEDs in the literature

The comparison between the scope of assessment described in articles, programmes and standards does not express a fully overlapping picture. There is more overlap between articles and programmes, although programmes rarely explain in detail the end uses considered in the assessment. On the other hand, the standards analysed use a boundary more focused on a whole-life approach and on the analysis of specific types of buildings (Fig. 5). However, the boundary system used in the evaluation does not seem either transparent or standardised.

Lifecycle assessments often refer to the Lifecycle Cost, though a substantial part of sources recognise its importance also from an energy point of view. Considering the overall picture, it is possible to intuit a prevalence in the debate (articles) of the theme of PEBs over PEDs, as it takes place within the market of environmental certifications (standards). Regarding government programmes, the EU's push on PEDs is essential.

A Lifecycle PEB defines an energy-efficient building that produces more energy from on-site renewable sources than is needed in all phases of the building's lifecycle, with high self-consumption and energy flexibility (Ala-Juusela M., 2021; Powerhouse, 2023).

The lifecycle analysis consists of the addition to the operational phase of the LCEE, i.e., Initial, Recurrent and Demolition Embodied Energy calculated within standard EN 15978:2011. The calculation is performed on the Bill of Quantity and includes construction waste.

The energy balance (of final energy, primary non-renewable or total) can be verified over the entire lifecycle of the building (e.g., 50 years) or on an annual basis, and is mainly calculated between energy consumption and generation but it can also concern grid import and export (Barrutieta *et al.,* 2023).

Furthermore, it is possible to distinguish between physical and balance boundary (Voss *et al.,* 2012), with differences between on-site and off-site productions and a match between import and export. In most cases, the operational energy balance is calculated annually, although there are cases of monthly or daily balances. The end uses included in the balance may intuire una prevalenza nel dibattito del tema dei PEBs sui PEDs, cosi' come all'interno del mercato delle certificazioni ambientali. Per quanto riguarda i programmi di governo risulta invece importante la spinta dell'UE sui PEDs.

Un *Lifecycle* PEB definisce un edificio energeticamente efficiente che produce, tramite fonti rinnovabili in loco, piu' energia di quella necessaria in tutte le fasi del ciclo di vita dell'edificio con elevato auto-consumo e flessibilità energetica (Ala Juusela, 2021; Powerhouse, 2023).

L'analisi sul ciclo di vita è costituito dall'aggiunta, alla fase *operational*, della LCEE, ovvero *Initial*, *Recurrent* e *Demolition Embodied Energy* calcolabile all'interno del framework EN 15978:2011. Il calcolo viene eseguito sulla *Bill of Quantity* e comprende la quota di materiale destinata a sfrido durante le operazioni di cantiere.

Il bilancio energetico (di energia finale, primaria non-rinnovabile o totale) puo' essere verificato sull'intero ciclo di vita dell'edificio (es. 50 anni) o su base annua, e viene principalmente calcolato tra *energy consumption* e *generation*, ma può anche riguardare *grid import* e *export* (Barrutieta *et al*., 2023).

Inoltre, è possibile distinguere tra *physical* e *balance boundary* (Voss *et al.,* 2012), con differenze tra produzioni *on-site* e *off-site* e *match* tra *import* e *export*. Nella maggior parte dei casi il bilancio energetico *operational* viene effettuato su base annua, sebbene possa essere calcolato anche su base mensile o giornaliera. Gli usi finali inclusi nel bilancio possono riguardare i consumi *building-related* (HVAC, DHW, Lighting) e includere *Plug load/Appliances*.

È importante notare come il grado di sviluppo e standardizzazione dei processi di calcolo dell'EE, necessiti di approfondimenti e non sempre garantisca la confrontabilità dei risultati, specie se paragonato alla prassi consolidata dei processi di calcolo dell'OE.

Tra gli indicatori maggiormente monitorati tra PEBs si citano il consumo di energia finale e primaria (totale e non rinnovabile), le emissioni di CO_{2eq} e la quota di produzione (annuale) in loco da fonti rinnovabili rispetto all'autoconsumo, mentre valori di benchmark quantitativo per LCA, oltre la verifica del bilancio "negativo", vengono individuati nei sistemi di rating LBC e Minergie-A (Moore *et al.,* 2019).

Conclusione

Il contributo intende evidenziare lo stato del dibattito sui PEBs e PEDs in relazione al perimetro di valutazione di analisi LCA e contestualmente, mediante una *gap analysis*, individuare i principali ostacoli che ne limitano lo sviluppo.

Dall'analisi della letteratura scientifica e dal recepimento e attuazione da parte di programmi, standard e quadro normativo emerge come il dibattito su PEBs e PEDs sia ancora limitato e la loro definizione scarsamente condivisa, specialmente in relazione agli impatti sull'intero ciclo di vita.

Le fonti che approfondiscono tali aspetti, evidenziate nella ricerca, possono essere utilizzate per lo sviluppo di definizioni, di assunzioni di calcolo e del perimetro di analisi, con l'obiettivo addizionale del superamento delle barriere all'implementazione presentate. Vengono inoltre forniti spunti per la valutazione e possibili misure per il raggiungimento degli obiettivi *energy-positive*.

Possibili ulteriori approfondimenti di ricerca riguardano lo sviluppo di scenari di analisi LCA, con diversi *boundary systems*

concern building-related consumption (HVAC, DHW, Lighting) as well as Plug load/Appliances.

However, it is important to note that the state of development and standardisation of the EE calculation processes needs to be investigated and does not always guarantee robust results, especially when compared to the established practice of the OE calculation processes.

Among the most monitored indicators in the PEBs, we mention the consumption of final and primary energy (total and non-renewable), CO_{2eq} emissions and the percentage of on-site production (annual) from renewable sources, compared to self-consumption. At the same time, quantitative benchmark values for LCA exceeding the "negative" balance are identified in the LBC and Minergie-A rating systems (Moore *et al.,* 2019).

Conclusion

This paper highlights the state of the debate on PEBs and PEDs in relation to the scope of assessment of LCA analysis and contextually, through a gap analysis, to identify the main obstacles that limit their development.

From the analysis of the scientific literature and the application of programmes, standards and regulatory frameworks, it emerges that the debate on PEBs and PEDs is still limited and their definition is scarcely shared, especially concerning impacts over the entire lifecycle.

The sources that deepen these aspects, highlighted in the research, can be used as common ground for developing definitions, calculating assumptions and scope of assessment, with the additional objective of overcoming implementation barriers. Moreover, suggestions for the evaluation and possible measures to achieve the energy-positive goals are provided.

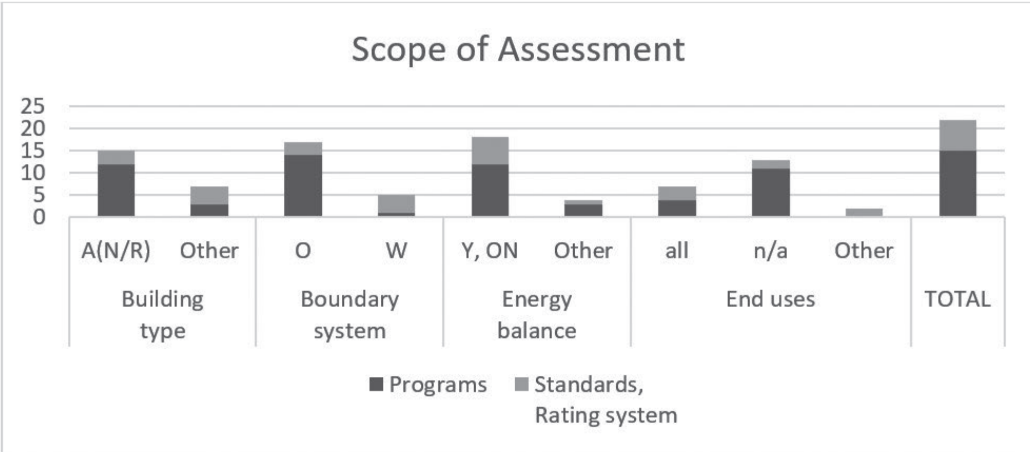
Further research insights concern the development of LCA scenarios with different boundary systems and contexts, which allow to identify intervention priorities and minimum requirements for achieving the Net-positive objectives. Finally, it is essential to compare the estimates made in the design phase and to measure post-construction impacts.

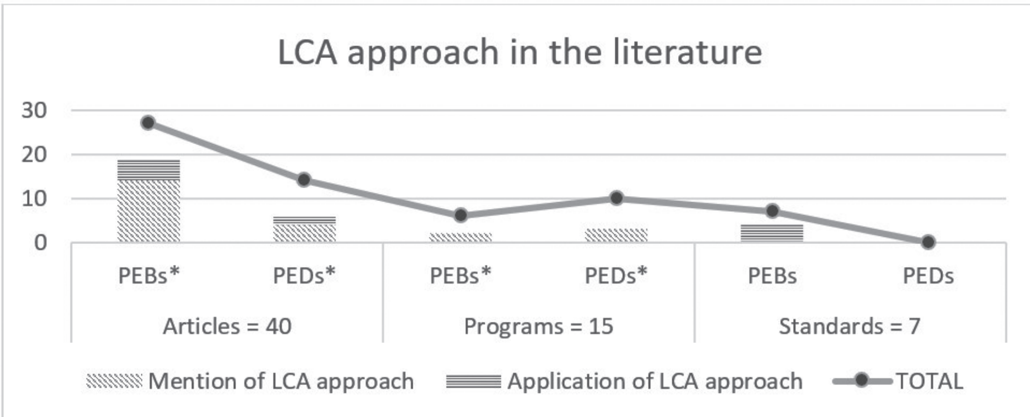
Net-positive architecture opens a reflection on the change the regenerative paradigm can cause in the design process, on the use and end-of-life of one or a network of buildings, as well as on the methods of intervention in different urban contexts, on the design approaches to different scales and the principles of technological integration. The positive energy balance is the objective of a strategy that is based on analysis carried out on the entire lifecycle, which foresees the application of active and passive design strategies such as: the reduction of needs, also through Information and Communication Technologies and Building Management Systems, the production of renewable energy, and the reduction of consumption from non-renewable sources or sources with high GHG and polluting emissions. On the other hand, the impacts of construction sites are reduced using materials and installation processes with low Embodied Energy and a high index of renewability, and integrated by offsetting actions.

The application of Net-positive projects can support the energy transition only if effectively evaluated over the entire lifecycle and within a shared strategic vision implemented by national regulations, as occurred in the case of NZEBs, in compliance with targets that allow the reversal of the environmental degradation in progress.

04 | Perimetro di valutazione in Programmi e Standard
Scope of assessment in Programs and Standards

05 | Diffusione del LCA nelle fonti analizzate. * fonti che menzionavano sia PEBs che PEDs (e LCA), pertanto viene inclusi 2 volte. Le fonti che menzionavano EE e LCC sono state inserite tra quelle con LCA approach
*Diffusion of the LCA in the analysed sources. * sources mentioning both PEBs and PEDs (and LCA), therefore included 2 times. Sources mentioning EE and LCC were included among those with the LCA approach*





e contesto, che consentano di individuare priorità di intervento e requisiti minimi per raggiungimento degli obiettivi *Net-positive*. Risulta, infine, fondamentale il confronto tra le stime effettuate in fase di progetto e la misurazione degli impatti post-costruzione.
La *Net-positive* architecture apre una riflessione sul cambiamento che il paradigma rigenerativo può comportare sul processo progettuale, sull'uso e fine vita di uno o una rete di manufatti edilizi, oltre che sulle metodologie di intervento in diversi contesti urbani, sugli approcci progettuali alle diverse scale e sui principi di integrazione tecnologica.
Il bilancio energetico positivo è l'obiettivo di una strategia che si basa su analisi effettuate sull'intero ciclo di vita, che preveda l'applicazione di strategie di design attivo e passivo come la riduzione del fabbisogno, anche mediante *Information and Communication Technologies* e *Building Management Systems*, la produzione di energia rinnovabile e la contrazione dei consumi da fonti non rinnovabili o ad alte emissioni di GHG e inquinanti. Dall'altro lato, gli impatti dei cantieri vengono ridimensionati dall'uso di materiali e di processi di posa a bassa *Embodied Energy* ed elevato indice di rinnovabilità, e integrati da azioni di *offsetting*.
La realizzazione di progetti *Net-positive*, se effettivamente valutati sull'intero ciclo di vita, può rappresentare un sostegno alla transizione energetica solo se inserito in rete all'interno di una visione strategica condivisa e recepita dalle normative nazionali, come avvenuto nel caso degli NZEB, nel rispetto di *target* che consentano l'inversione del deperimento ambientale in corso.

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