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Review

Indirect Effects of High-Performance Buildings at Household and Community Level: A Systematic Literature Review

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Abstract: Towards a carbon-neutral society, the building sector has a pivotal role with still a great potential for improvement. A new generation of buildings is rising but, to set a more ambitious shift in the paradigm and to fully justify the additional efforts (technological and economic) needed to fill the gap between net zero and plus energy performances, it is essential to consider not only the direct effects, but also all the indirect impacts. However, research conducted in the last decade solely focuses on the direct effects, mainly energy savings, while the indirect impacts neither have a clear identity nor terminology and a defined list of the impacts and methodologies for their quantification is still missing. With these premises, a systematic literature review on the current state of the art was performed in this work, with the aim of (i) investigating the heterogeneous terminology used for such indirect effects, (ii) identifying a final potential list of impacts both at the household and at the community level and (iii) their macro-categorizations, and (iv) exploring the current implemented methodologies and indicators for an economic quantification. As a final result of the analysis, the authors propose a unique terminology for addressing the indirect effects of high-performance buildings. This paper sets the needed basis and common ground for future research in this field, meant to economically quantify the indirect effects in the building sector.

Keywords: indirect effects; co-benefits; multiple benefits; co-impacts; high-performance buildings

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1. Introduction

With the goal of a carbon-neutral society, the objectives set off by the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in 2021 (https://ukcop26.org/, accessed on 10 December 2022) seal the abatement of net emissions globally by 2050 and set the limitation in temperatures' increase to 1.5 °C, speeding up the phase out of fossil fuels, while protecting communities and natural ecosystems. This is in line with the Sustainable Development Goals of the United Nations (https://sdgs.un.org/goals, accessed on 10 December 2022), which highlight the importance of sustainable cities and communities and all the aspects related to health, wellbeing, and the preservation and coexistence of humans and natural ecosystems. The building sector plays a key role, being responsible for a major amount of energy consumptions and foremost greenhouse gas emissions [1]. In this direction and with the aim of changing the paradigm in the construction practice, the Energy Performance Building Directive (EPBD) 2010/31/EU [2], and its subsequent recasts, established a policy framework to support the decarbonization of the EU building stock by 2050 [3]. Through these tools, the EU Commission, beside placing the building stock and its need for renovation under the spotlight, looks also at the new constructions by setting the mandatory target of nearly Zero Energy Buildings (nZEBs) from 31 December 2020. Meanwhile, research has already moved beyond the concept of nZEBs, aiming for the so-called Plus (or Positive) Energy Buildings (PEBs). In the current state, the definition of high-performance buildings is currently still controversial [4] and their evolution has moved in synchronization with the equipment and the design concepts used, along with the contemporaneity of the science [5]. Consequently, nowadays, an overabundance of related undefined and overlapping terminology exists, e.g., nZEBs, passive houses, Net Zero Energy Buildings (NZEBs), PEBs, as well as various definitions, government policies, and construction activities [6]. Focusing on PEBs, there are three main Horizon projects working on the definition of plus energy multi-family residential buildings: (i) Cultural-E project (https://www.cultural-e.eu/, accessed on accessed on 10 December 2022); (ii) EXCESS project (https://positive-energy-buildings.eu/, accessed on 10 December 2022); (iii) synikia project (https://www.synikia.eu/, accessed on accessed on 10 December 2022). PEBs represent the next evolutionary step after NZEBs. The definition of a PEB is still under discussion among the three projects, but for the scope of this work, PEBs are considered energy-efficient buildings that produce more energy than the consumed amount on a yearly basis [4–8], and the excess energy can be stored or delivered to surrounding buildings to supply their energy needs [9,10]. The PEB target is achievable thanks to the synergy between high-performance technologies, the latest construction techniques, and an optimized design aimed at minimizing energy usage. In addition, the integration with the grid allows for an interaction with the surrounding buildings, increasing the positive impact also for the neighborhood [11]. However, the higher efficiency comes with an extra cost to reach positiveness in the balance, due to the implemented cutting-edge solutions [12]. To cope with this aspect, it is strategic to start including in the overall evaluation also all the added-values connected with PEBs and their technologies, which stand beyond the mere balance of the main conventional parameters, namely energy consumptions, net energy costs, and carbon emissions. Any additional benefit and related impacts that can have a significant influence on the building value must be included in the building evaluation [13]. These ancillary features still represent an unclear and undefined territory not commonly considered in the final building's overall performance due to the difficulty in their identification, estimation, and, to a final extent, quantification.

Some studies, such as [13–16] highlighted the potential relevance of the so-called side effects, which can present both a local and a wider societal impact. However, at the current state, a unanimity in the identification, definition, and quantification of such co-impacts is still missing and some main points are highly controversial. The available references focus only on a few aspects, lacking a comprehensive list of the potential side effect of a PEB, as well as of a solid common ground including the definition, the potential impact, and the methodology for their quantification. In the state of practice, investors lack guidelines on how to quantify and monetize the co-benefits and, when an attempt exists, these aspects are generally evaluated merely in a qualitative way. However, a real understanding of the value and impact of the indirect effects can be a key supportive tool for the estimation of different measures and investments to the final extent of enhancing the understanding, acceptance, promotion, and spread of PEBs among the community. This is even more important in the current historical period and worldwide energy crisis, where PEBs, thanks to their lower dependence from the energy grid, low energy need, and on-site Renewable Energy Source (RES) production, can contribute to reducing the imported energy from fossil fuels while guaranteeing energy security for their users.

With these premises, in order to achieve a complete consideration of the building as a whole and to integrate all the potential effects coming from the construction of a high-performance building, we conducted a systematic literature review following the PRISMA guidelines [17], with the aim at filling the gap in the topic by providing a resolutive identification of the potential indirect effects associated with technology implementation, their categorization into macro-areas and levels of analysis, and the current approaches for quantification. Finally, considering the results of the current state, the authors provide recommendations on the terminology to be used to address such indirect effects. The presented work is intended to set the basis for future research and to reach the final aim of providing professionals and stakeholders with ready-to-use indicators to economically quantify the identified indirect effects connected with high-performance buildings. Following Section 1, in Section 2, the systematic process for identifying and extrapolating the relevant documents in the literature is explained, from the search into the database to the ultimate filtering for obtaining the final sample. In Section 3, an investigation of the different terminologies used in currently for indicating side effects related to high-performance buildings is presented, along with their clustering into macro-categories and a final list of potential side effects at both the household and community level. In addition, the existing current methodologies for economic quantification are overviewed. In Section 4, besides the highlights from this work, the authors also propose a unique and common terminology and definition for addressing such indirect effects in the building sector for future research in this field.

2. Materials and Methods

To perform a structured analysis of the available works, the PRISMA guidelines [17] were used for data collection and the preliminary selection of the documents. In Figure 1, the PRISMA flow chart for reporting data from systematic reviews is used: for each phase, reported also in the text, the different steps are described, along with the number of remaining documents in the sample (in red color).

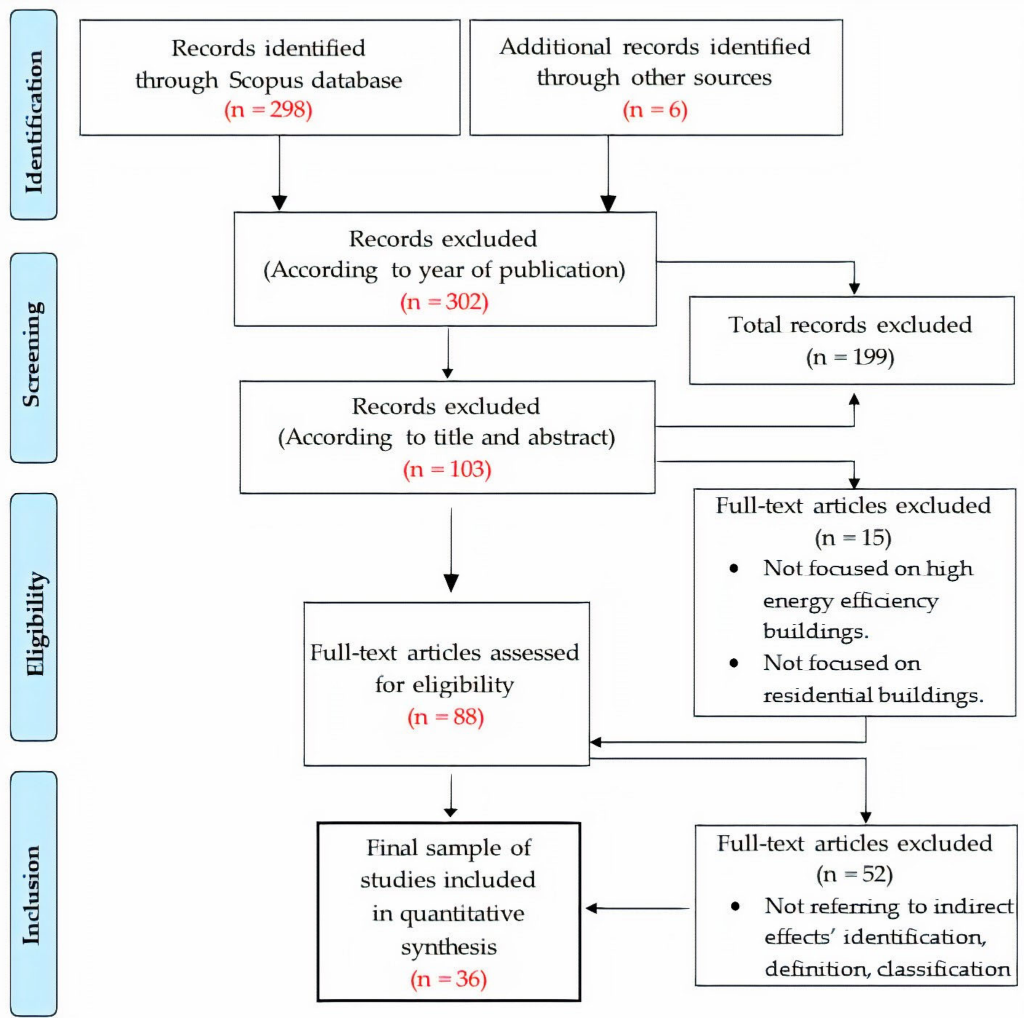

Figure 1. Flowchart adapted from the PRISMA guidelines [17] for the literature review database creation.

The literature search focused on the co-benefits related to high-performance buildings, with the aim of collecting information about the (a) definition of the term and identification of the indirect effects and the (b) clustering into macro-categories of such impacts. The final list of publications to be analyzed was obtained from an iterative process, which first involved an analysis of the literature to identify synonymous terms and review the search string until the results stop changing. The definitive search string was developed to ensure that all relevant articles were included. Firstly, the search started with the term "*co-benefit*", the terminology that is mostly adopted in the literature when discussing the construction and energy sectors. Afterwards, the term "*co-benefit*" was integrated with terms often used as synonyms, i.e., "*co-impact*", "*ancillary benefit*", "*side effect*", "*multiple benefit*", and "*non-energy benefit*". The gathered documents refer to various fields of interest, e.g., building renovation, residential, energy efficiency, green buildings, climate change, etc. A descriptive summary of the sample, according to the subject area and year trend, is reported in Figure 2a,b. To restrict the findings to high-performance buildings, the results were refined by including the terms "*plus energy houses/buildings*" or "*passive houses*" and "*nearly zero energy buildings*" or "*net zero energy buildings*".

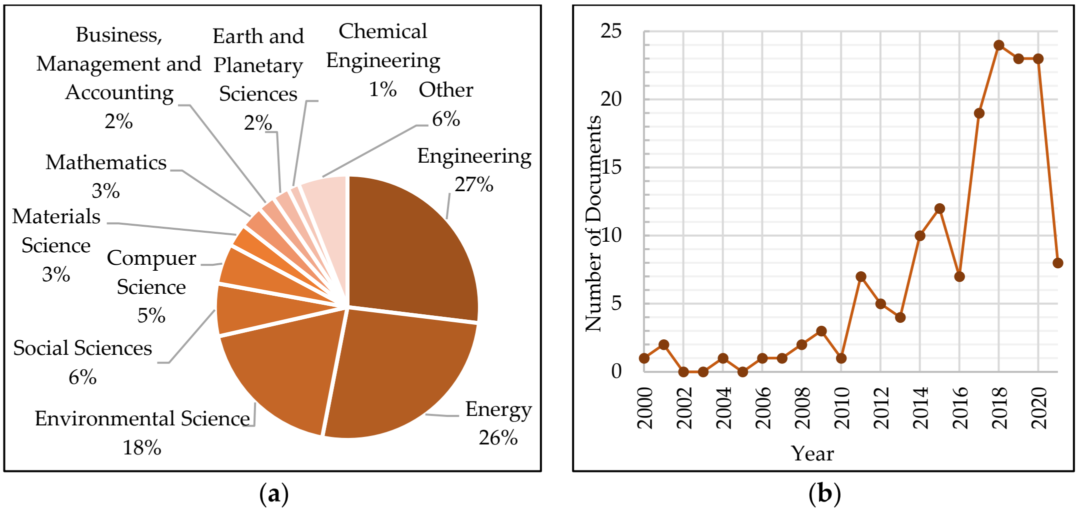

Figure 2. Analysis of the documents' final sample. (**a**) Documents by subject area from the initial subset of 298 documents. (**b**) Documents by year trend for the final subset of 298 documents (source: Scopus).

For the process, the Scopus (https://www.scopus.com, accessed on 20 December 2022) database was the main source for the various scientific papers in the preliminary state-of-the-art analysis, returning 298 documents (Figure 2). Scopus was chosen since it is the largest database of peer-reviewed scientific literature and it provides a comprehensive overview of worldwide research. In addition, for robustness, Google Scholar (https://scholar.google.com, accessed on 20 December 2022) was searched but only 6 additional articles were found and added to the sample, resulting in a final sample of 304 elements.

At this point, a **screening** (Figure 1) process was performed. A preliminary analysis targeting the year of publication and the relevance of the paper was conducted. Only the articles starting from the year 2000 were found relevant, reducing the sample then to 302 documents. Secondly, the documents were filtered according to (i) title and (ii) abstract. The articles that contained the right terms (according to keywords) but dealt with irrelevant topics were deleted, mainly due to their reference to other sectors rather than the building one. In fact, inspecting the works that were then eliminated, we verified that they took into consideration particular sectors, such as AFOLU (agriculture, forestry, other land uses), electricity, transport, and industry. As a second step, the residual documents were then checked and filtered by reading their abstracts. At the end of this selection process, 199 scientific papers were excluded and 103 were identified, including different research topics.

To validate the **eligibility** (Figure 1) of this sample, the articles were filtered based on their significance for our research area (i.e., building sector but specifically high-performance buildings) by means of full text reading, focusing on their relation to energy-efficient buildings with residential use. In total, 15 documents were additionally removed because they were not pertinent to the criteria, and among the remaining set, 9 documents dealt specifically with Plus Energy Houses, while the rest referred to energy-efficient buildings in general, such as nearly zero energy buildings, passive houses, and other similar buildings.

To complete the **inclusion** (Figure 1) into the final sample of documents, a last selection was performed by strictly identifying, on the one hand, the articles relating to the identification and definition of indirect effects, and, on the other hand, those relating to their classification in areas of interest. In total, 52 records were removed due to the lack of focus on the building sector. The final subset for the literature analysis consisted of 36 documents.

Starting from this final sample, the literature review was conducted with the aim of: (i) investigating the different terminology currently used in for indicating side effects related to high-performance buildings; (ii) dividing such indirect effects into macro-categories; (iii) outlining the final list of potential side effects at the household and community level; (iv) pointing out existing current methodologies for the economic quantification.

3. Results and Discussion

3.1. Terminology

The analysis highlighted that the terminology currently used to describe indirect effects of high-performance buildings is still varied and undefined. In fact, different terms are used depending on the field of interest and on the specific study itself, including "*co-benefits*", "*co-impacts*", "*ancillary benefits*", "*side effects*", "*ancillary impacts*", "*multiple benefits*", and "*non-energy benefits*", and a unique common definition is still not available.

In 2013, Jiang et al. [18] pointed out in their work that the term "*co-benefit*", and foremost its implications, has not yet received particular attention in the construction sector and that, consequently, there are no definitions of it in this area of interest. Despite the research trend having grown in the last 5 years, the need for filling this gap in the building sector is still evident. In 2018, Deng et al. [19] conducted a systematic literature review, which returned a classification of the co-benefits based on type, mitigation sector, and geography. Eight sectors were identified: AFOLU (*agriculture, forestry, and other land use*), electricity, transport, residential, governmental, industrial, marine, and building sector. According to the study, this latter one had the smallest percentage of publications on the topic (1.4%, Figure 3).

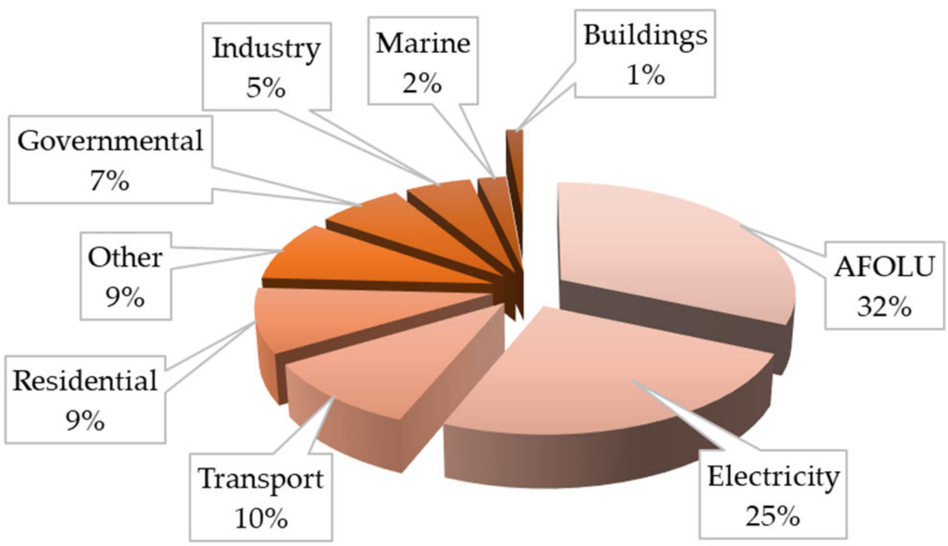

Figure 3. Documents referring to "*co-benefits*" divided per sector (Elaborated from: [19]).

A summary on the main significant uses of the term co-benefits and related terms is presented in Table 1. In Figure 4, the references are presented according to their timeline. As reported, the term "*co-benefit*" was coined in 2001 by the Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report [20] and it was initially used within the context of climate change, indicating the effects coming from the implementation of policies referring to different grounds, in particular, the mitigation of climate change and the reduction of greenhouse gas emissions. The premise was that most policies which are issued to address such direct effects can also lead to other ancillary but equally important benefits, linked to the objectives of development, sustainability, and equity [21]. In the same report, the concept of "*co-impact*" was also introduced but with a wider meaning that includes not only positive but also negative side effects. In addition to the above mentioned terminology, the term "*ancillary benefit*" was also used in the same IPCC document, indicated as the side effects resulting from the policies set exclusively for climate change and GHG emissions mitigation which can actually have an impact also on the efficient use of resources (e.g., reduction in local and regional air pollutants' emissions from fossil fuels) and on the fields of transportation, land-use practices, agriculture, fuel security, and employment [20].

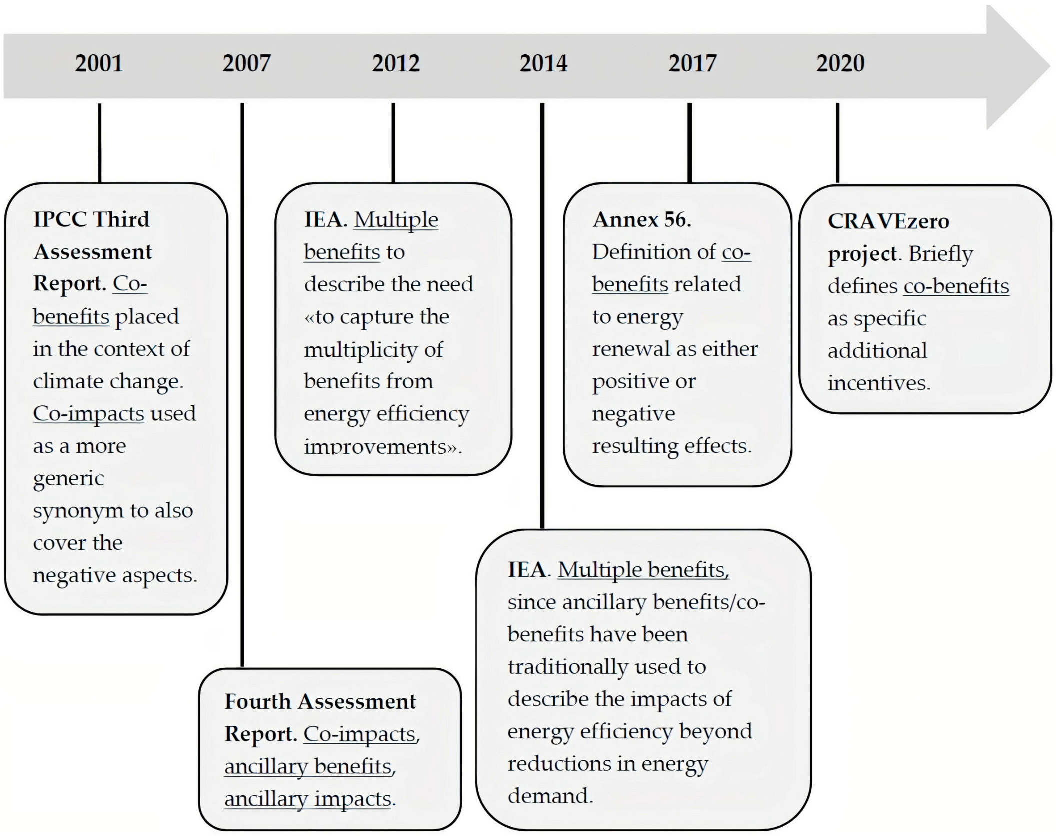

Figure 4. Timeline of the use of various terms to indicate the co-benefits in different documents from 2001 to 2020.

From that IPCC document, different studies delivered their own interpretation of the definitions and transposed them according to their research target. In this direction, the International Energy Agency (IEA) recommends the use of the term "*multiple benefits*" in order to capture the whole multiplicity of effects deriving from energy efficiency improvements [22]. According to the IEA, the reason for this choice is that it evokes the numerous and heterogeneous outcomes of energy efficiency actions and it has been used before by the US Environmental Protection Agency (EPA). From their perspective, the terms "*co-benefits*", "*non-energy benefits*", and "*ancillary benefits*" are all included within "*multiple benefits*". In 2014, the Fifth Assessment Report issued by the IPCC [21] brought some novelties in the definition of co-benefits. A distinction no longer exists between "*co-benefits*" and "*ancillary benefits*", but they are all incorporated and defined as the positive effects resulting from the policies or measures aimed at one specific objective, but which might have other final goals. However, the net effect on overall social welfare is not yet evaluated and, due to their uncertain nature, local circumstances and implemented practices can have an effect on them [21]. In the same year, the International Energy Agency also used the terminology "*multiple benefits*" [22], being ancillary benefits or co-benefits that traditionally describe energy efficiency measures' impacts, beyond reductions in the energy demand—i.e., the benefits that occur in addition to a single prioritized policy goal. According to the IEA [22], various sources use all these terms interchangeably with "*multiple benefits*"; however the use of "*multiple benefits*" is recommended so as to avoid a pre-emptive prioritization of different benefits; in this way, a wider meaning is given to the terminology and, thus, a great variety of aspects are included, which can be to different extents of interest to multiple stakeholders.

Finally, in 2017, the first more comprehensive definition of "*co-benefits*" in the construction sector was proposed by Annex-56 [23], a project with the goal of developing a new methodology for cost effective renovation in existing buildings. In this instance, the term "*co-benefits*" was adopted as related to energy retrofit strategies and indicates both the positive and negative effects, beyond energy savings and carbon emissions' reduction, which may arise from high-efficiency energy buildings or from energy-related renovation actions [23]. Even though, at this time, for the first time there was the clear willingness to also include in the analysis potential negative effects, it is necessary to highlight how the use of the word "*benefits*" still generally resembles just a positive acceptation. Recently, in the 2020 H2020 CRAVEzero project [24], a set of co-benefits were defined in terms of the economic value to be included in the business model of nZEBs.

Table 1. State-of-the-art analysis on the use of the term to address side effects from high-performance buildings, referring to different available documentation from 2001 to 2020.

Year	Definition	Field	Source
2001	"*Co-benefits*" are the effects coming from the implementation of policies referring to different grounds, focusing in particular on the mitigation of climate change and greenhouse gas emissions reduction. It is acknowledged that most policies issued to address such direct effects can also have other pivotal ancillary benefits, linked to the objectives of development, sustainability, and equity. "*Co-impact*" has a wider meaning that includes not only positive, but also negative side effects. The term "*ancillary benefits*" indicates the side effects resulting from policies set exclusively for climate change and GHG emissions mitigation, but that can actually have an impact also on the efficient use of resources and on the fields of transportation, land-use practices, agriculture, fuel security, and employment.	Climate change mitigation	[20]
2007	"*Co-benefits*" are the result of policies issued with different scopes at the same time, considering that most policies designed to address the mitigation of GHG emissions mitigation can have other, but equally important, effects. The term "*co-impact*" is also used in a more generic sense to cover both the positive and negative side of the benefits.	Climate change mitigation	[25]
2012	The term "*Multiple benefits*" in used to capture the whole multiplicity of effects deriving from energy efficiency improvements, as it evokes the numerous and heterogeneous outcomes of energy efficiency actions. This terminology includes "*co-benefits*", "*non-energy benefits*", and "*ancillary benefits*", and it is so far the broadest and most inclusive terminology relating to the outcomes of energy efficiency policy. No rank or prioritization as primary or secondary or energy or non-energy benefits is proposed.	Energy efficiency	[15]
2013	"*Co-benefits*" are mentioned in the context of urban climate, referring to the implementation of initiatives and policies that simultaneously contribute to reducing the pressure on man-made global climate change, while solving local environmental problems in cities. From this approach, other potential positive developmental impacts can rise, like an improvement in citizen health, energy security and income generation.	Urban climate	[26]

Table 1. *Cont.*

Year	Definition	Field	Source
2014	A distinction no longer exists between "*co-benefits*" and "*ancillary benefits*", with the latter terminology used the most. They are defined as the positive effects resulting from actions and policies aimed at one specific objective, but which might have other additional final scopes. Their uncertain nature is often influenced by local circumstances and implemented practices. The net effect on overall social welfare is not yet evaluated.	Climate change mitigation	[21]
2014	The term "*multiple benefits*" is used to indicate ancillary benefits or co-benefits that traditionally describe the impacts from energy efficiency measures beyond common direct effects. "*Multiple benefits*" is recommended since it does not allow a pre-emptive prioritization of different benefits, and it includes a wider meaning where a great variety of aspects are included, as of interest to various stakeholders.	Energy efficiency	[22]
2016	The term "*co-benefits*" is analyzed in the context of urban climate action and cities, based on the evidence that citizens are more likely to act on climate change and to support governments that take action on climate change if the wider co-benefits of those actions are emphasized.	Urban climate and cities	[27]
2017	"*Co-benefits*" are both the positive and negative effects that can arise from high-efficiency energy buildings and from an energy-related building renovation, beyond the reduction in energy consumptions and GHG emissions.	Energy efficiency and buildings' renovation	[23]
2018	"*Co-benefits*" are categorized into private and macro-economic perspectives. According to the first one, they represent the overall increment for the owner of the building value resulting from a renovation process, besides the direct benefits. From the latter point of view, the co-benefits represent the indirect benefits from investments towards energy performances of buildings' improvements, accruing to the society at large.	Buildings' renovation	[28]
2019	"*Co-benefit*" is also defined as "an additional positive adaptation (mitigation) effect that can be achieved from a planning and/or policy measure aimed at improving mitigation (adaptation)".	Climate adaptation and mitigation in cities	[29,30]
2020	"*Benefits*" are mentioned related to equity, considering the historical contributions to the accumulation of GHGs in conjunction with the intra- and inter-generational distribution of the benefits and burdens of mitigation policies.	Climate change mitigation and sustainable development	[31]
2020	The term "*co-benefits*" is used and an attempt towards the identification of their economic value is proposed, towards the implementation into business models.	NZEBs	[24]

3.2. Macro-Categories

The lack of a common definition of the indirect effects has also led to the consequent difficulty in classifying their macro and subcategories. In fact, despite several documents in the sample approach on the topic, very few of them offer a clear categorization. Some attempts are reported hereafter, and their growth over time is summarized in Figure 5.

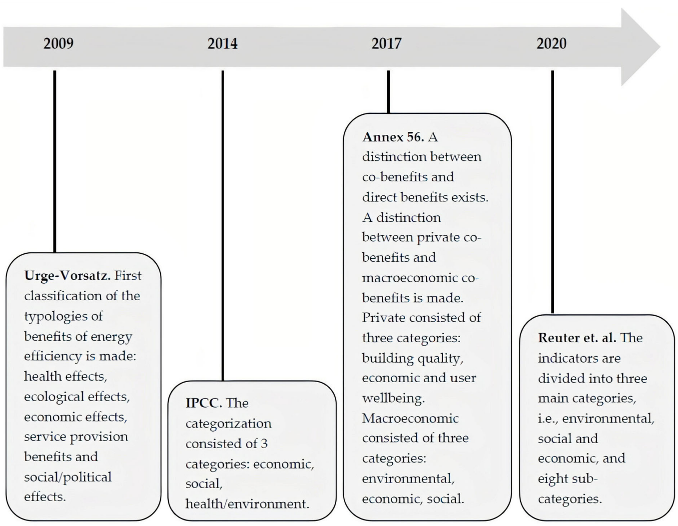

Figure 5. Timeline of the main different categorizations of indirect effects in different documents from 2009 to 2020 [21,23,32,33].

Among the first works that classified the typology of benefits related to energy efficiency and energy use in the building sector, there is the one conducted in 2009 by Ürge-Vorsatz et al. [32]. In this work, five categories of benefits were identified: health effects, ecological, economic, service provision benefits, and social/political impacts. Successively, in 2014, the IPCC Working Group III dedicated an entire chapter of its Fifth Assessment [21] to the building sector, where potential co-benefits and adverse side effects associated with mitigation actions were analyzed in buildings. Three categories constitute this IPCC differentiation: economic, social, and health/environment. In the above-mentioned Annex-56 project [23], a more articulated classification of the co-benefits was proposed, differentiated into private and macro-economic ones. According to the authors, a societal or macro-economic perspective is required for policymakers in order to demonstrate that the policies implemented for the reduction in energy and emissions in the building sector may be used to reach other objectives, such as economic and social development, sustainability, and equity. Comparatively, a private perspective refers to building owners and promoters, who are mainly interested in the economic value of a building and the value added by energy related renovation measures, and, thus, in the potentially increased willingness to pay for the building. Referring to the latter private scale, co-benefits can have both a positive and a negative impact on the building and its owner, and they are divided into three categories: building quality, economic, and user well-being [23]. On the other side, the other three main categories constitute the macro-economic perspective: environmental, economic, and social (Table 2).

Table 2. Categorization of co-benefits in the IEA Annex-56 project (Elaborated from: [23]).

Direct Benefits	Co-Benefits	
	Private	Macro-Economic
• Energy use reduction • Carbon emission reduction • Life cycle cost reduction	• Building quality • Economic • User well-being	• Environmental • Economic • Social

Another significant work in the field was conducted by Reuter et al. [33], which aims at building a comprehensive set of indicators for measuring multiple benefits of energy efficiency interventions (Table 3).

Table 3. Classification scheme for multiple benefits in Reuter et al. (Elaborated from: [33]).

Multiple Benefits		
Environmental	Social	Economic
• Energy/resource management • Global and local pollutants	• Energy poverty • Quality of life	• Innovation/competitiveness • Macro-economic • Micro-economic • Energy security/energy delivery

With this scope, three main groups were identified by the authors: environmental, social, and economic. In addition to this, some sub-categories were proposed for each main cluster (Table 3): (i) “energy/resource management” and “global and local pollutants” referring to the environmental category; (ii) “energy poverty” and “quality of life” (which includes health and well-being) for the social group; (iii) “innovation/competitiveness”, “macro-economic”, “micro-economic”, and “energy security/energy delivery”, concerning the economic sphere.

Starting from the above-mentioned studies, we identified a comprehensive model that could include the largest number of indirect effects related to energy-efficient buildings and their technologies, which is summarized in Figure 6.

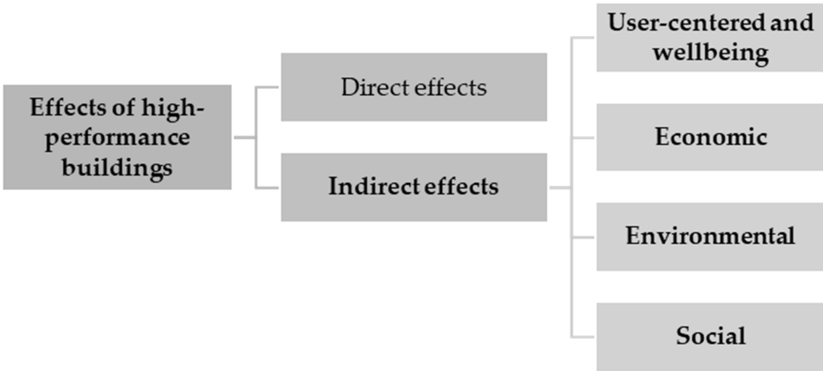

Figure 6. Categorization of the indirect effects from high-performance buildings, both at household and community level.

As a first level of categorization, impacts can refer to two different levels, namely: (i) the household level, i.e., for the building owner or user such as increased user comfort, fewer problems with building physics, improved maintenance, etc.; (ii) the community level, i.e., health benefits, decreased mortality or morbidity, job creation, energy security, impact on climate change, etc. As a second categorization, four macro-categories were identified: user-centered and wellbeing, economic, environmental, and social.

3.3. Final List

Each macro-category shown in Figure 6 includes a certain number of side effects, as disclosed in Table 4: nine for the "user well-being" category, six of economic type shared between "household" and "community" level, four for the "environmental" category, and four for the "social" category.

Table 4. Proposed list of indirect effects divided into categories (in brackets), both at household and community level.

Household	**Direct effects**	• Reduction in energy consumption costs (**Economic**)		
	Indirect effects	• Thermal comfort • Acoustic comfort • Visual comfort • Indoor air quality • Building physics • Health improvement • Ease of use • Safety • Resilience to climate change (**User-centered and wellbeing**)	• Lower energy bills • Lower maintenance costs • Increase in the value of the building • Increase in productivity (**Economic**)	
Community	**Direct effects**	• Reduction in CO_2 emissions • Reduction in energy use (**Environmental**)		
	Indirect effects	• Lower cost of energy • New business opportunities (**Economic**)	• Reduction in atmospheric pollution • Reduction in construction/demolition waste • Environmental protection and enhancement • Mitigation of climate change (**Environmental**)	• Mortality/morbidity/hospitalization reduction • Urban heat island mitigation • Energy security • Aesthetics of the building/neighborhood enhancement (**Social**)

Hereafter, each individual macro-category is explained starting from the literature findings. Each single co-impact is described in Tables 5–8.

3.3.1. User-Centered and Wellbeing

The users' wellbeing and indoor environmental quality conditions in the indoor environment have been under the spotlight for years, finally being recommended also by the EU Directive 2018/844 [34], which recommends that the building and its technical systems have "the ability to adapt its operation mode in response to the needs of the occupant while paying due attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and the ability to report on energy use", as well as providing "higher comfort levels and wellbeing for their occupants and improve health". In this direction, in the last decade various certifications have included or even focused on users' wellbeing, e.g., LEED (https://www.usgbc.org/leed, accessed on 4 June 2022), BREEAM (https://www.breeam.com/, accessed on 4 June 2022), WELL Building Standard (https://www.wellcertified.com/, accessed on 4 June 2022).

Given its importance, we included user well-being as a dedicated category despite, in other works, it generally being included as a sub-category of the "social" area (e.g., in [33]). The indirect effects related to this category directly affect the people using the building and range from comfort and convenience to health, users' perceptions, adaptation, and interactions with the building itself and its systems.

This category includes the following co-impact, more extensively described in Table 5: thermal comfort, acoustic comfort, visual comfort, indoor air quality, health improvement, building physics (increase in useful areas), ease of use, safety, climate change resilience.

Table 5. User-centered and well-being indirect effects: list and description.

User-Centered and Wellbeing		
Level	**Indirect Effect**	**Description**
Household level	**Thermal comfort**	Comfort is a subjective condition that affects both the body and the mind, and it can vary from person to person. Physical, psychological, and behavioral personal differences are known to affect comfort perception and adaptation mechanisms, as well as culture and other societal dynamics, namely individual, organizational, and social norms [23,35,36].
	Acoustic comfort	We speak of acoustic comfort when, immersed in a sound field, we are in conditions of well-being, in relation to the activity that we are performing [37]. This can also be evaluated in a very subjective way but the technologies and solutions that allow us to obtain it are quite universal [23,35,36].
	Visual comfort	Lighting within an environment, whether artificial or natural, is considered to be primarily responsible for visual comfort; inadequate lighting causes general feelings of discomfort and eye fatigue that can adversely affect user comfort, health, and performance [23,35,36].
	Indoor air quality	It is the only indicator among those that make up the IEQ that explicitly refers to healthiness rather than comfort, and, for this reason, should be considered as the most important. IAQ directly relates to comfort and psychological and physical health of the users, depending also on the frequency and the duration of the exposure [21,25,30–33,35,36,38].
	Building physics	The different uses and the presence of innovative materials is one of the features that has led to the increase in useful areas inside the house, especially thanks to thinner but no less insulated walls [23,35,36].
	Health improvement	An overall improvement in health can happen with an actual improvement of IEQ conditions. Recognized health benefits include reduced respiratory illness, reduced allergies and asthma, and reduced sick building syndrome symptoms [39].
	Ease of use	The adjustment of many parameters of the house (temperature, lighting, windows, household appliances, etc.) can be conducted directly from the smartphone or laptop. This can certainly have a positive feedback on everyday life in terms of convenience, but the ease of use may not be so obvious, especially for certain categories of people, particularly the elderly [23].
	Safety	Building elements at the latest standards provides fewer risks such as accidents, fire, or intrusion [23]. Smart systems ensure more secure access control; in order to authenticate authorized persons, modern buildings can detect irregular intrusions and even alert an emergency center if necessary. Sensors continuously monitor the environment, alerting in case of anomalies such as a fire.

3.3.2. Economic

According to the EU Directive 2018/844 [34], the implementation of high-efficiency alternative systems in buildings should be encouraged by Member States, considering their technological, functional, and economic feasibility, while at the same time also addressing and enhancing healthy indoor environmental conditions. Regarding the economic sphere of indirect impacts resulting from high-performance buildings, both a user and a societal level are involved, since both individual households and, more broadly, the community can be affected by such effects.

Within the "household level", economic effects are lower energy bills, lower maintenance costs, increase in the value of the building that, therefore, leads to a greater ease of selling/renting it, and increase in productivity (related to the smart working). Regarding the "community level", economic effects consist mainly of lower costs of energy and new business opportunities. Further descriptions are provided in Table 6.

Table 6. Economic indirect effects: list and description.

Economic		
Level	**Indirect Effect**	**Description**
Household level	**Lower energy bills**	Reducing the energy needs and consequent costs [23,24,35,36].
	Lower maintenance costs	Lower charges are expected due to fluctuations in energy prices, which in turn will have a positive effect on operating and maintenance costs [23,24,35,36].
	Increase in the value of the building	The property value of a building is impacted by its energy performance [23,35]. In fact, green certifications are recognized as a profitable investment that leads to an increase in rents between 4% and 21% [40,41].
	Increase in productivity	Having fewer indoor pollutants; better acoustics, lighting, and satisfaction levels; and the ability to concentrate can lead to higher productivity when working from home [39].
Community level	**Lower cost of energy**	Potential to create smart micro-grids at the neighborhood level to share the surplus of renewable energy produced. Reduced infrastructure needed and consequent lower charges. Higher possibility to negotiate the energy price due to the significant level of grid independence [24].
	New business opportunities	New business opportunities by increasing the attractiveness for energy service companies (ESCOs). Potential impact on GDP [23].

3.3.3. Environmental

The transition to Plus Energy Buildings and efficient buildings in general is necessary to achieve the objectives of sustainable development prescribed by IPCC Reports in Climate Change [42] and the current EPBD Directive [34] and subsequent recast. It is key that the decarbonization of the building sector takes place as quickly as possible, bringing with itself all the related positive impacts over society as identified in this work: reduction in atmospheric pollution, reduction in construction/demolition waste, environmental resource protection (ecosystems and biodiversity), mitigation of climate change (Table 7).

3.3.4. Social

Towards a carbon-neutral society, the evaluation of the indirect effects shall embrace a wider perspective, going beyond the boundaries of the single building and its inhabitants and expanding its effects all over the community. Social impacts, as from the name, no longer act solely on the individual or family units of the building but have broader impact on communities of people all over the world. Among them, the authors identified: mortality and morbidity reduction, urban heat island mitigation, energy security, and aesthetic of the building as part of the neighborhood enhancement (Table 8).

Table 7. Environmental indirect effects: list and description.

Environmental		
Level	**Indirect Effect**	**Description**
Community level	**Reduction in atmospheric pollution**	An increase in outdoor air quality is achieved by means of an increased use of energy from renewable sources and a consequent reduction in the use of fossil fuels [23,42,43]. In addition to this, less waste substances, and therefore less air pollution, result from the increased efficiency and the connected smart grids. High-performance buildings could be even more effective at reducing pollution in streets and open roads if coupled with the design solutions of green infrastructures, such as green walls and roofs, contribute towards reducing air pollution in urban areas [44].
	Reduction in construction/demolition waste	In the process of reducing environmental loads and minimizing construction and demolition waste, a key role is also played through the application of life cycle assessment techniques (LCAs). It allows, in practice, one to acquire awareness of environmental damage in each of the phases that make up the life cycle of a product (and therefore also of a building): from production, transport, use, recycling, and reuse until disposal [23,36].
	Environmental protection and enhancement	A significant reduction in CO_2 emission is achieved by means of the wider implementation of Renewable Energy Sources (RESs), enhancing also the improvement of environmental resource conservation due in particular to lower levels of air pollution [45]. In this way, ecosystem preservation and biodiversity protection are enriched by the transition to clean energy [21,22].
	Resilience to climate change	In addition to the great energy efficiency, Plus Energy Buildings are able to ensure adequate levels of comfort, helping in this way also to reduce the effects related to climate change (e.g., heat waves). Heat waves, in fact, besides having a significant impact on mortality and morbidity, can also lead to problems in electricity distributions due to peaks in demand caused by the use of air conditioners [46]. In this perspective, independence from the electric grid can be achieved due to energy provided by the micro-generation of energy through RESs. Therefore, especially with the current worldwide energy crisis in mind, this feature proves even more advantageous for a safe energy transition that embraces the present and future challenges.
	Urban heat island mitigation	Reduced energy needs especially in cooling season. Application of advanced technologies (e.g., green roofs, façades, and balconies) that contribute to increasing indoor comfort and to reducing the urban heat island [14,19].
	Mitigation of climate change	Reduction in energy consumption and emissions contributing to mitigating the effects of climate change as a side effect [21,22].

Table 8. Social indirect effects: list and description.

Social		
Level	**Indirect Effect**	**Description**
Community level	**Mortality/morbidity/hospitalization reduction**	Improved comfort and indoor air quality (household level). Reduced CO_2 emissions have an effect on outdoor pollution (community level). These have an impact at household and community level which can be associated with a reduced morbidity potential of indoor and outdoor environment, with consequent avoided hospital admissions, medicines prescribed, restricted activity days, and productivity losses [14,20,32].
	Energy security	Lower dependence from the energy grid, thanks to the low energy need and the local RES production. At larger scale, reduction in imported energy from fossil fuels [6,22,43].
	Aesthetics of the building/neighborhood enhancement	Aesthetic improvement presents a potential impact on building value and market relevance [23].

3.4. Economic Quantification

Another main challenge that subsists in the evaluation of the indirect effects is the identification of a structured and repeatable methodology for monetary quantification. In fact, such side effects are generally addressed in a qualitative way, and thus they are neither properly integrated in a comprehensive evaluation of the building's performance nor in business models. A future step forward in this direction could significantly support the promotion, acceptance, and spread of high-performance buildings and related technologies among the community.

In order to understand the current available methodologies for the quantification and monetary estimation of the indirect effects, a review was conducted, limited only to the documents retrieved for the identification of such effects. Few of the included documents achieve an economic evaluation, and, for these, the indicators and methodologies for monetary quantification are summarized in Table 9.

Table 9. Indicators and methodologies for economic and monetary evaluation of the indirect effects.

Economic Evaluation		
Indirect Effect	**Methodology**	**Quantification and Monetary Values**
Overall improvement in IEQ conditions	In Almeida et al., 2017 [23], the cost assessment is performed referring to specific renovation interventions linked to the resulting co-benefits, by means of a methodology based on a life cycle cost approach, generally assuming a private economic perspective which includes: the initial investment cost, (ii) replacement cost during the (remaining) lifetime of the building, (iii) running costs, (iv) maintenance and operational costs. This approach is to be performed dynamically, discounting future costs and benefits. Social costs include external costs and benefits, excluding taxes and subsidies. A monetary quantification is achieved in terms of monetised permanent annual benefit to society and refers to a health improvement (see specific benefit below).	Additional costs calculated based on specific renovation packages in specific geo-located case studies. Monetised permanent annual benefit to society [23]: • health benefits from improved indoor climate = EUR 42–88 billion
Health improvement	According to [39], in order to calculate health benefits, the potential percentage reductions in health effects were multiplied by the size of the affected population or by the number of health effects experienced. To estimate economic benefits, the percentage reductions in health effects were multiplied by the annual costs of the health effects. The costs were based on U.S. published estimates incorporating both direct health care costs and indirect productivity costs (e.g., value of lost work). In [24], reduced sick leaves were used as indicators in the cost-benefit analysis of nZEBs. In [23], the monetary quantification is performed at a societal level.	Estimated in U.S. annual potential productivity gains/annual savings (1996 USD) [39]: • Reduced respiratory illness = USD 6–14 billion • Reduced allergies and asthma = USD 1–4 billion • Reduced sick building syndrome symptoms = USD 10–30 billion • Improved worker performance from changes in thermal environment and lighting = USD 20–160 billion Estimated in [24]: • Reduced sick leaves = −10% • Additional investment = 170 EUR/m^2 • Return of investment ≥ 10 years • Profit over 30 years = 154 EUR/m^2 Monetised permanent annual benefit to society [23]: • Health benefits from improved indoor climate EUR 42–88 billion
Lower energy bills and maintenance costs	Payback of the initial investment through a decrease in energy bills and maintenance costs during the life cycle of the building [23,24]. According to [23], the willingness to pay for certain retrofit interventions depends also on the expectation of future reduced costs on energy bills and building operations.	Estimated in case studies [24]: • The total energy saving amounts to 60 kWh/m^2a • The annual value for the reduced value for energy costs amounts to 12 EUR/m^2a Monetised permanent annual benefit to society [23]: • Lower energy bills EUR 52–75 billion
Increase in the value of the building	In [40], according to the current state, three main procedures can be used for calculating the added-value due to an improvement in building's energy performance: the hedonic pricing approach, the method based on the direct comparison between transaction prices, and the method based on the willingness to payback investments on energy efficiency measures. In addition, in the document a classical method to calculate the net present value of costs of energy savings is discussed. In [24], an estimation is offered in terms of reduced vacancy, higher rent, and faster rental.	In [40]: • Estimated increase in the price of residential assets = 3–8% • Estimated increase in residential rents = 3–5% • Estimated increase in the price of commercial assets = 10–20% • Estimated increase in commercial rents = 2–5% Differences occur depending on regions and countries, as well as different property types. Estimated in [24]: • Reduced vacancy = −1% • Additional investment = 170 EUR/m^2 • Return of investment ≥ 15 years • Profit over 30 years = 81 EUR/m^2 • Higher rent = +5% • Additional investment = 170 EUR/m^2 • Return of investment = >10 years • Profit over 30 years = 221 EUR/m^2 • Faster rental = +5 months • Additional investment = 170 EUR/m^2 • Return of investment ≥ 10 years • Profit over 30 years = 111 EUR/m^2
Increase in productivity	For office buildings, calculation of total savings through a 1% of productivity improvement, using average salary costs for employee and quantity of employees [24].	Estimated in [24]: • Increased productivity = +1% • Additional investment = 170 EUR/m^2 • Return of investment ≥ 5 years • Profit over 30 years = 347 EUR/m^2
New business opportunities	Increase in GDP growth [23].	Estimated in [23], depending on the level of investments: • Benefits to GDP = EUR 153–291 billion
Job creation	Rise in jobs [23].	Estimated in [23]: • Rise in jobs for 760,000–1,480,000 people
Reduction in atmospheric pollution	Calculation of air pollution-related mortality, by means of the method of the WHO's global burden of disease study (GBD) for 2010 [47]. In [23], monetised as annual benefit to society.	Estimated in [47]: • Combined ($PM_{2.5}$ and O_3 related) global mortality attributable to air pollution in 2010 = 3.3 million • Global estimate for $PM_{2.5}$ related mortality = 3.15 million per year Monetised permanent annual benefit to society [23]: • Reduced outlay on subsidies and reduced air pollution from energy production = EUR 9–12 billion
Reduction in construction/demolition waste	Calculation of waste reduction through the application of life cycle assessment (LCA) methodologies [23].	N/A

This overview underlines that indirect effects refer to different levels, from the household to the community, therefore embracing different economic perspectives. On the one side, from a real estate perspective, the economic value of a building and the added value that derives from an energy retrofit are the main indicators and, therefore, the indirect effects can potentially increase tenants' or buyers' willingness to pay. On the other side, for policymakers, a societal or macro-economic perspective is needed to show how a policy issued mainly with an emission or energy reduction goal may also support other objectives such as sustainability and social development.

Starting from the household level and the benefits associated with an improvement of indoor environmental quality conditions, in [23], the cost assessment is linked to specific retrofit interventions and refers mainly to a private economic perspective, where costs are evaluated based on a life cycle cost approach. The evaluation addresses especially the topics of thermal, visual comfort, and indoor air quality (IAQ). The latter is generally associated with health improvements, which, in the work of Fisk [39], are evaluated based on the annual costs of health effects, embracing both direct health care and indirect productivity costs. In fact, as highlighted also by [24], a decrease in health effects leads to an increase in productivity, especially when considering office environments.

Some authors [23,24], consider lower energy bills as an economic benefit linked to a decrease in energy consumptions) and maintenance costs can be easily directly associated with retrofit interventions or the implementation of innovative technologies, as pointed out in the works conducted [23,24]. In this case, the willingness to pay (WTP) of building owners and tenants for certain energy efficiency measures (EEMs) depends on the expectations of reduction in future operation costs. Nevertheless, the integration of EEMs and technologies brings an increase in the building value [40], raising the WTP for a certain final product and introducing a significant leverage tool in the business models of buildings.

Moving to the community level, high-performance buildings and their need of qualified professionals can create new business opportunities, up to the final extent of an increase in the gross domestic product (GDP) of a country [23]. The reduction in outdoor atmospheric pollution directly affects the related mortality and the global burden of disease [47]. The impact calculated in terms of disability-adjusted life years (DALYs) or deaths avoided can be monetized by means of the value of statistical life (VSL) or the value of a life year (VOLY) [20,21,25,42,48]. Finally, the reduction in construction and demolition waste play an important role [23]. This can be calculated by means of life cycle assessment (LCA) methodologies and monetized by means of market value of waste and recycling services, according to the EU Commission's Guide to Cost-Benefit Analysis.

All the other indirect effects, which still are the vast majority, have not yet been quantified in the analyzed literature. Among the research community, there is no consensus on the methods to be applied and, thus, a price tag to be associated with each indirect effect is still missing. This could be achieved with further research and a multidisciplinary approach.

In the current state of this topic, guidelines and common approaches for the monetary quantification of the indirect effects are still missing yet urgently needed. According to the main economic methodologies for the evaluation of environmental assets, two main potential approaches are used: (i) monetary evaluation, whose reference indicator is the willingness to pay (WTP), and (ii) non-monetary evaluation, which refer to multicriteria analysis.

The monetary evaluation includes direct and indirect methods: in the latter one, the detected or declared value of an attribute concerns another asset, whereas in the direct approach the detected or declared value directly concerns the asset that is being evaluated. Both these methodologies can refer either to detected or declared preferences. The detected ones consist of the WTP inferred from the real behavior of the subjects, based on the market transactions of goods related to the assets to be estimated. The declared ones are the WTP directly stated by potential users by means of an interview or choice experiment. Various methods embrace different approaches, as shown in Table 10.

Table 10. Methods for the monetary evaluation of environmental assets.

	Preferences Detected	Preferences Declared
Direct	Market price	Contingent evaluation Contingent raking
Indirect	Defensive expenses Cost of restoration Cost of the travel Hedonic price	

In the future outlooks of this work, starting from these methodologies, a first attempt at a structured monetary quantification will be performed. In particular, for what concerns the indirect effects at the household level, a contingent choice experiment will be conducted among selected users in different countries and economic contexts in order to obtain their WTP for a certain benefit. For the community level, on the other hand, a direct costing approach will be implemented by means of associating, when possible, a straight monetary value to a clearly quantifiable source (i.e., a performance indicator) of co-benefit.

4. Conclusions

The road towards the energy transition requires an extra effort from the building sector, which is called to look at high-performance buildings as the new consolidate paradigm. Nevertheless, despite the great energy potential of such buildings, there are still many barriers for their wide implementation, among them their economic viability, foremost regarding the potential extra costs due to the integration of cutting-edge technologies and systems.

Looking at business models, considering merely the energy savings of high-performance buildings may tell just a part of the story, leaving out a wide range of other additional indirect benefits that can contribute to justifying the extra cost. In fact, these side effects are generally neglected in practice, due to a lack of clear identification, categorization, and, to a final extent, economic quantification.

In this paper, through a systematic literature review, some fundamental points in the field have been set as first steps towards accounting for indirect effects in high-performance buildings' overall performance evaluation and business models. In this direction, the following highlights have been achieved:

- An investigation of the different terminologies used to address the indirect effects of high-performance buildings.
- The identification of a frame to classify such indirect effects based on the subject that benefits or is affected by the co-impact (household/community) and category (user-centered and wellbeing, economic, environmental, social).
- The finalization of a list of potential impacts eligible for the economical quantification.
- Overview of the current approaches and indicators available currently for monetary quantification.

After this overview and critical analysis of the results from the current state-of-the-art, as a final step of this work, the authors propose a unique and common terminology for such indirect effects, as well as their definition. Therefore, the term "*co-impacts*" is recommended as the most suitable for the building sector, and the following definition is proposed:

Co-impacts are the added positive and negative values, other than the direct and measurable impacts, which derive from high-energy efficient buildings and related technologies.

Co-impacts can be household co-impacts if they influence the user's well-being and household economy, or community co-impacts if they have wider economic, social, and environmental effects.

This definition partially embraces the IPCC's first definition of 2001 [20]. The term "*co-impacts*" is selected since it resembles and includes both the positive (namely, *co-benefits*) and negative effects (namely, *adverse side effects*) related to a high-performance building.

This review was meant to set a common ground and solid basis for further research in this direction, which is clearly needed to achieve an economic quantification and therefore support stakeholders in the building sector. Further research in the field will enhance the penetration of high-performance buildings in the market, enabling comprehensive business models that take into account not only the direct effects, but also all the multiple benefits.

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