Enhancing sustainability in construction: analysis of high-efficiency solutions for NZEBs in the Marche Region

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Abstract. Renewable energy, green energy, environmental sustainability, and interventions aimed at the construction of low-carbon structures are now major topics of interest for a sustainable, economic and social development of the city. For several years the international scenario has presented guidelines and protocols for the energy-environmental sustainability of buildings, often aimed at awarding a high sustainability label. In Italy one of the most used certification systems is the ITACA Protocol, recently updated by the UNI /PDR 2023, which through a series of criteria identifies global indicators on sustainability, energy efficiency and indoor comfort of the building. In this context, an multi-criteria analysis was developed to identify highly energy-efficient solutions for nearly Zero-Energy Buildings (NZEB) in the Marche region.

1 Introduction

In an era marked by fast urbanization and a growing awareness of the urgent need to combat climate change, the concept of energy transition has emerged as a pivotal force shaping the future of urban environments. Energy, in all its forms, underpins the functioning of modern cities, from powering our homes and industries to fueling our transportation networks [1]. However, the ways in which we produce and consume energy have profound implications for both the environment and overall human well-being.

As cities continue to expand and evolve, it is imperative to address the complex challenges associated with energy use in urban environments while simultaneously exploring innovative and sustainable solutions [2].

Exploring possible pathways for sustainable energy transition requires interdisciplinary knowledge concerning advanced technologies that drive the transition.

Bin Chen et all.[3] identified four themes on sustainable energy transition pathways. The first is sustainable energy economics and management; the second is renewable energy generation and consumption; the third is the environmental impacts of energy systems and the last is electric vehicle and energy storage. In [4] is recognized the city as epicenters of innovation, economic activity, and cultural diversity.

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The city are described as the engine of progress, drawing millions of people in search of opportunities, connectivity, and a higher quality of life. Yet, this urbanization has brought about an array of unprecedented challenges, and energy stands prominently among them.

J.Z. Thellufsen et al.[5] considers the cities as not only major consumers of energy but also significant contributors to greenhouse gas emissions and environmental degradation. The implications of this are far-reaching and affecting air quality, public health, and the stability of the Earth's climate. Recognizing the pressing need to address these challenges, the concept of energy transition has gained traction worldwide [6], [7], [8].

Michael Child and al.[9] deal with the main challenges lies in the decarbonization of urban energy systems. Many cities still rely heavily on fossil fuels for their energy needs, which not only contributes to greenhouse gas emissions, but also exposes them to vulnerabilities associated with finite fossil fuel resources.

The transition to cleaner energy sources, such as wind, solar and hydropower, requires substantial investment in renewable energy infrastructure and technologies, and a coordinated effort to phase out carbon-intensive energy production [10].

Another critical aspect of urban energy transition pertains to energy efficiency. In [11] are described the effects of green buildings on IEQ and occupant health, highlighting sustainable architectural practices that promote good health.

Urban areas are rife with opportunities for optimizing energy use through innovative building designs, advanced heating and cooling systems, and smart grid technologies [12], [13].

Achieving greater energy efficiency not only reduces environmental impact but also offers economic benefits and enhances energy security. Additionally, in [14] it describes the transition to electric vehicles, efficient public transportation networks and alternative mobility solutions. The urban transportation systems play a pivotal role in the energy landscape of cities is crucial for reducing the carbon footprint of urban transport [15], [16], [17].

This shift requires comprehensive planning, investment, and behavioral changes among urban dwellers. Infact, governments at various levels must play a proactive role. Local governments hold a unique position in promoting energy transition. They are often the closest to the needs and aspirations of their citizens, enabling them to enact policies and initiatives that align with the specific challenges and opportunities of their urban environments. Municipal governments as [18], [19], [20], [21], [22] can encourage renewable energy adoption, enforce energy efficiency standards in buildings, and facilitate sustainable transportation solutions.

In Italy was recently improved the ITACA protocol (Institute for Innovation and Transparency of Contracts and Environmental Sustainability) [23], [24] administered by UNI-ITACA. The ITACA protocol green building rating system encourages an integrated design approach, with a points scheme that allots credits for building design features deemed to improve sustainability, which includes reductions in energy use and improvements in indoor and outdoor environment quality [25], [26].

The scientific literature also explores the different solutions and best practices that have emerged, showcasing the potential for urban environments to become models of energy sustainability [27].

In Erkinai Derkenbaeva et al.[28] it is introduced that the concept of Positive Energy Districts (PEDs) has emerged to facilitate the energy transition and contribute to climate neutrality through energy efficiency and net zero energy balance.

In Zaheer Allam et al.[29] it is describing the '15-Minute City' concept that can be poised as a potent solution to re-structure cities for increased sustainability, inclusivity, and economic equity, through locally implemented fiscal mechanisms.

Other studies explore the characteristics of urban built settings that support psychological health [30].

2 Region strategies and sustainable certifications

Sustainability objectives in the Marche Region (Italy) are outlined in the Regional Sustainable Development Strategy (https://www.regione.marche.it/Entra-in-Regione/Sviluppo-Sostenibile/Strategia-Regionale-Sviluppo-Sostenibile}{SRSvS}) which specifically defines the framework for the Strategic Environmental Assessment (SEA). For this purpose, contribution indicators are identified, which must be mandatory in the SEA, related to the context indicators of the Strategy, along with the identification of their respective targets.

The Marche Region, particularly in the section - Land Reclamation, Energy Sources, Waste, and Quarries and Mines, participates as a project partner in the 'LC Districts' project (Towards low carbon city districts through the improvement of regional policies), funded within the framework of the Interreg Europe 2014-2020 Interregional Cooperation Program, falling under Priority Axis 3, "Low-carbon economy" (https://www.interregeurope.eu/good-practices/itaca-protocol-urban-scale).

A low-carbon city is an approach to sustainable urbanization that focuses on reducing the anthropogenic carbon footprint by minimizing or eliminating the use of energy derived from fossil fuels. It combines the characteristics of a low-carbon society and a low-carbon economy while supporting partnerships among governments, the private sector, and civil society. A defining feature of low-carbon areas is the presence of buildings meeting energy efficiency standards.

2.1 ITACA Protocol

The ITACA Protocol [31] was developed as a tool to evaluate the level of energy and environmental sustainability of buildings. It assesses building performance not only in terms of energy consumption and efficiency but also in terms of environmental impact and human health, promoting the construction of innovative buildings with reduced water consumption and low-energy materials, ensuring a high level of comfort.

The aim of the protocol is the construction of increasingly innovative buildings, NZEB, with reduced water and material consumption which in their production involve low energy consumption and at the same time guarantee a high level of welfare.

The use of this tool is regulated by the (https://www.accredia.it/documento/rt-33-rev-01-prescrizioni-per-laccreditamento-degli-organismi-di-ispezione-di-tipo-a-b-e-c-ai-sensi-della-norma-uni-cei-en-isoiec-17020-in-conformita%C2%92-al-%C2%93protocollo-itaca%C2%94/**)**.

Regulation, which has established the national system of accreditation and certification, conducted on a voluntary basis, to support national and regional policies for the development of environmental sustainability in construction.

The reference practice adopts a multicriteria analysis system for the evaluation of environmental sustainability, structured according to the following three hierarchical levels:

- Domains
- Categories
- Criteria

The areas represent macro-themes that are considered significant for the evaluation of the environmental sustainability of a building. This document considers 6 areas of assessment of listed below:

- Area A. Site development and regeneration;
- Area B. Energy and resource consumption;
- Area C. Environmental loads;
- Area D. Indoor environmental quality;
- Area E. Quality of service;
- Area H. Adaptation to climate change.

Each area encompasses multiple categories (in varying numbers, depending on the area considered), each of which addresses a specific aspect of the respective theme.

The categories, in turn, are further divided into criteria, each of which delves into a specific aspect of the corresponding category. The criteria, in the end, represent the assessment items of the method and are used to characterize the building's performance at the beginning of the evaluation process.

In addition to the three primary hierarchical levels (criteria name and code, assessment area, belonging category), each "criterion sheet" also includes the following entries:

- Requirement: Expresses the quality objective to be pursued;
- Performance Indicator: Allows for quantifying the building's performance concerning each criterion;
- Measurement Unit: If the indicator is quantitative, this specifies the measurement unit;
- Performance Scale: To be used as a reference for normalizing the indicator within the range from -1 to +5;
- Method and Verification Tools: To be used for characterizing the value of the indicator;
- Criterion Weight: The degree of importance assigned to the criterion within the entire evaluation tool.

Figure 1 shows the criteria of the ITACA protocol divider into the areas.

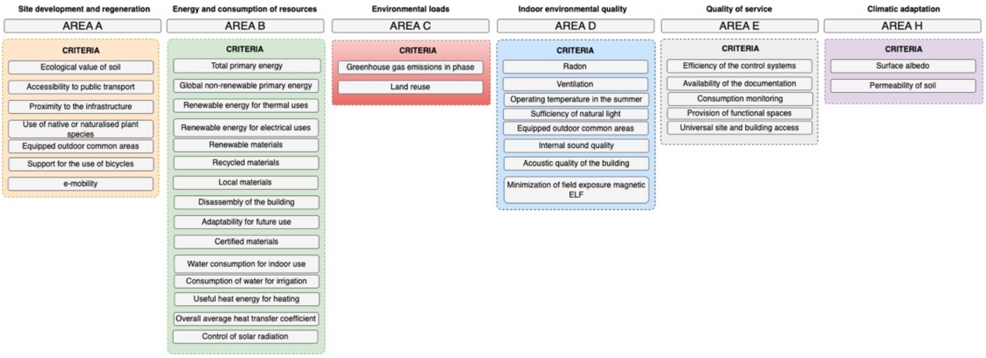

Figure 1. ITACA protocol PDR/UNI 13:2023.

The method for calculating the energy-environmental performance, which is proposed by the protocol, is based on the attribution of a score based on the performance of the building with respect to the aspects that are considered, according to the scheme of the green building challenge.

The score varies from a negative value -1 to the value of excellence +5.

In particular, the performance scale is developed according to the scheme shown in **Table 1**.

Table 1. Interpretation of rating scale scores.

-1	It represents a performance below the standard and current practice.
0	It represents the minimum acceptable performance defined by the laws or regulations in force, or, if there are no reference regulations, it represents the current practice.
1	It represents a slight improvement in performance compared with current regulations and practice.
2	It represents a moderate improvement in performance compared with current regulations and practice.
3	It represents a significant improvement in performance compared to existing regulations and common practice. It is to be considered as the current best practice.
4	It represents a moderate increase in current best practice.
5	It represents a considerably advanced performance compared to the current best practice, of an experimental nature.

The final score of the intervention is calculated in reference to the scores obtained for "Quality of the building" and "Quality of the location".

In particular, the scores of areas B, C, D, E of category A.3 are aggregated to produce the score relative to the quality of the building (SQE), as regards the score relative to the quality of the localization (SQL) corresponds to the only score of category A.1.

Finally, to assess the overall quality of the construction performance (S), the final score of the intervention is calculated as:

$$S = 0.05\ SQL + 0.95\ SQE \qquad (1)$$

3 Multi-criteria analysis in the Marche Region

In this context, a multi-criteria analysis has been developed to identify high-energy efficiency solutions for Nearly Zero Energy Buildings (NZEBs) in the Marche region.

This analysis aims to assess various options and provide an overview of best practices to achieve the energy sustainability goals set by the ITACA Protocol.

The sustainability analysis comprised an initial phase involving the assessment of the building's current state, followed by simulations of the interventions summarized in the **Table 2**.

Table 2. Key Sustainability criteria for building design and construction.

Cod.	Type of interventions	Description
IN1	Thermal Insulation	Use of high-efficiency insulation materials to minimize heat loss through walls, roof, and floor.

IN2	Acoustic Insulation	Use of materials and design strategies to minimize sound transmission and enhance acoustic comfort within the building.
IN3	Ventilation Systems	Implementation of mechanical ventilation systems (VMC) to ensure adequate air exchange without compromising energy efficiency.
IN4	Renewable Energy Sources	Integration of renewable energy sources such as photovoltaic solar panels, geothermal systems, or other sustainable technologies to generate energy within the building.
IN5	Energy Efficiency of Systems	Use of electronic equipment and systems with high energy efficiency, such as LED lights, high-efficiency appliances, and low-energy heating/cooling systems.
IN7	Bioclimatic Architecture	Building design taking into account local climatic conditions to maximize the use of natural resources such as sunlight and natural ventilation.
IN8	Energy Control and Management Systems	Installation of advanced energy management systems to monitor and intelligently regulate energy consumption in response to building needs.
IN9	Low Environmental Impact Materials	Selection of low-impact environmental construction materials, minimizing the use of non-renewable resources and environmentally harmful substances.
IN10	Monitoring and Maintenance	Implementation of energy efficiency monitoring systems and regular maintenance programs to ensure that systems maintain optimal performance over time.
IN11	Occupant Engagement	Raising awareness among occupants about the importance of energy conservation and promoting sustainable daily practices.

Table 3 provides a comprehensive overview of interventions dedicated to the creation of Nearly Zero Energy Buildings (NZEB) within the Marche region, serving as a compelling case study.

Encompassing a spectrum of interventions, from renovation to ground-up construction, the table accentuates pivotal attributes such as building type, climate area, construction year, adopted construction technology, and the sustainability quotient achieved by each structure.

Table 3. Overview of Cases in the Marche Region.

Cod.	Type of Intervention	Building Type	Climatic Area	Year of Construction	Construction Technology
A	Demolition and Reconstruction	Elementary School	Mountainous Areas	2018	Wooden Construction
B	Energy Retrofit	Commercial Office	Coastal Areas	1980	Traditional Techniques
C	New Construction	Residential Complex	Inland area	2021	Low Environmental Impact Materials
D	Retrofit	Historic Building	Mountainous Areas	18th century	Thermal Insulation

3.1 Results of the multi-criteria analysis and the future of eco-friendly buildings

The in-depth multi-criteria analysis has unveiled innovative and sustainable solutions, marking a significant evolution in eco-friendly development.

The integration of a comprehensive energy efficiency system emerges as a crucial step in realizing low-impact environmental buildings.

Carefully designed, this system is conceived to maximize energy efficiency, employing a strategic synergy of key components.

Emission reduction lies at the heart of this solution, making a substantial contribution to the overall sustainability of the building.

Low-impact environmental materials and efficient fixtures work synergistically to create a protective barrier against heat dispersion, providing an additional boost to energy consumption optimization.

Table 4 presents the detailed results of the multi-criteria analysis conducted for CASE B, aimed at a thorough evaluation of innovative solutions in the field of sustainable construction.

A particular focus was given to the in-depth examination of interventions IN1-IN5 (see Table 3).

In the last column, the criterion-by-criterion score is presented, derived from the combination of the first three interventions, considering innovative design solutions for bioclimatic and social architecture, with reference to interventions IN9-IN11 (see Table 3).

This comprehensive analysis provides a detailed perspective on the impact and effectiveness of the various solutions considered within the context of sustainable construction for CASE B. The data highlights the effectiveness of an integrated system for energy efficiency, providing a detailed overview of performance in terms of emission reduction, environmental impact, and energy consumption optimization.

Table 4. Results Table.

Criteria		Status quo	Window and door frames	Mechanical System	External thermal and acoustic insulation	Combined interventions (IN1-IN11)
A.1.1	Ecological value of soil	2,66	2,66	2,66	2,66	5
A.1.2	Accessibility to public transport	3,17	3,17	3,17	3,17	5
A.1.3	Proximity to the infrastructure	2,07	2,07	2,07	2,07	5
A.1.4	Proximity to services	-1	-1	-1	-1	3,95
A.2.1	Use of native or naturalised plant species	-1	-1	-1	-1	5
A.2.2	Equipped outdoor common areas	-1	-1	-1	-1	5
A.2.3	Support for the use of bicycles	-1	-1	-1	-1	0

A.2.4	e-mobility	0	5	5	5	4,92
B.1.1	Total primary energy	-1	5	-1	2,49	0,05
B.1.7	Global non-renewable primary energy	-1	0	-1	5	5
B.2.2	Renewable energy for thermal uses	-1	-1	-1	2	0,6
B.2.3	Renewable energy for electrical uses	0	0,2	0	4,76	4,76
B.3.3	Renewable materials	0,52	-1	0,52	5	5
B.3.4	Recycled materials	-1	-1	-1	0,22	0,22
B.3.5	Local materials	3,55	5	3,71	4,02	4,02
B.3.6	Disassembly of the building	-1	-1	-1	4,8	4,8
B.3.7	Adaptability for future use	2,35	4,8	2,35	4,67	4,67
B.3.8	Certified materials	-1	-1	-1	5	5
B4.3	Water consumption for indoor use	5	5	5	0,71	0,71
B.4.4	Consumption of water for irrigation	0,42	0,42	0,42	0,42	5
B.6.1	Useful heat energy for heating	0,42	0,42	0,42	0,42	5
B.6.2	Useful thermal energy for cooling	5	5	5	5	5
B.6.3	Overall average heat transfer coefficient	2,13	2,13	2,13	2,13	0
B.6.4	Control of solar radiation	0	0	0	2	2
C.1.2	Greenhouse gas emissions in phase operational	0	0	0	2	2
C.3.3	Land reuse	-1	-1	-1	-1	2,39
D.1.5	Radon	5	4,17	5	4,38	0
D.1.8	Ventilation	0	0	0	5	5
D.2.5	Operating temperature in the summer	5	5	5	5	-1

D.3.2	Sufficiency of natural light	-1	-1	-1	0	0
D.4.6	Internal sound quality	0	0	0	1	3
D.4.7	Acoustic quality of the building	0	0	0	0	3
D.5.1	Minimization of field exposure magnetic ELF	0	0	0	0	0
E.1.1	Efficiency of the control systems	0	0	5	4	4
E.2.1	Availability of the documentation technique	0	0	0	0	0
E.2.2	Consumption monitoring	0	0	5	4	4
E.3.1	Provision of functional spaces	0	0	0	0	0
E.4.1	Universal site and building access	0	0	0	0	0
H.1.1	Surface albedo	0	0	0	0	0
H.2.1	Permeability of soil	0	0	0	0	0
SQL		2,83	2,83	2,83	2,83	3,68
SQE		0,55	1,09	0,62	0,98	3,15
FINAL		0,7	1,2	0,7	1,1	3,2

In this analysis, we investigated how the protocol can be a valuable tool for the design of sustainable buildings.

Specifically, we highlighted how various interventions, such as installing efficient windows, optimizing systems, and using materials from renewable sources, can significantly enhance the sustainability level of a building.

In the last section, we demonstrated how the combined effect of these interventions, along with the integration of design solutions related to the site, services, and climate, contributes to achieving a score that reflects the proper implementation of good practices. This illustrates how thoughtful design, and the adoption of advanced energy solutions can translate into tangible results consistent with environmental sustainability principles.

The significance of these results is further underscored by their ability not only to meet the stringent requirements of the ITACA Protocol but also to pave a clear path for the design and construction of sustainable buildings in other regions.

The outlined model, with its versatility and adaptability, stands as a guiding beacon for future projects, contributing to shaping a shared vision of a future built with environmental responsibility and sustainability.

Its capacity to surpass the standards set by the ITACA Protocol suggests that it can be effectively applied in diverse geographical contexts, providing a solid foundation for the adoption of sustainable construction practices worldwide.

4 CONCLUSION

In summary, these results not only confirm adherence to the highest standards but also open the way for a significant shift in the approach to construction, promoting a reduced ecological footprint and more conscientious design.

The drawn conclusions emphasize the profound potential for transformation embedded within Sustainable building practies. This calls for a collaborative endeavor aimed at shaping a collective and environmentally conscious architectural landscape.

By recognizing the transformative impact of embracing sustainability in construction, there emerges an invitation for joint efforts and shared responsibility.

This collaborative approach seeks to transcend individual projects, fostering a community-wide commitment to sustainable architectural principles.

The vision is to cultivate an eco-conscious ethos that permeates the entire architectural realm, promoting practices that not only meet immediate needs but also contribute positively to the long-term well-being of both the built environment and the broader ecosystem.

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