Ann Ig. 2025 Jul-Aug; 37(5): 565-573 doi: 10.7416/ai.2025.2708. Epub 2025 May 13.

Environmental Sustainability in Next-Generation Hospitals. Identifying Needs and Requirements from Healthcare Organizations and Industry Stakeholders.

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Keywords: Hospital sustainability; sustainable healthcare; healthcare infrastructure; sustainability survey; next generation hospital
Parole chiave: Sostenibilità ospedaliera; sanità sostenibile; infrastruttura ospedaliera; survey sulla sostenibilità; next generation hospital

Abstract

Background. *Hospitals are among the most resource-intensive infrastructures, consuming significant amounts of energy, water, and materials while contributing 5.2% of global carbon dioxide emissions. Despite growing awareness and international commitments, hospitals face financial, structural, and operational barriers in implementing sustainability strategies.*
Study design. *The study assesses the maturity of healthcare stakeholders regarding environmental sustainability, exploring key drivers, barriers, and strategies for integrating sustainability into healthcare facilities.*
Methods. *A national web-based survey was conducted within the Joint Research Partnership Healthcare Infrastructures between November 2022 and January 2023, gathering 30 responses from 32 partners (94% participation rate). The analysis focuses on the environmental sustainability dimension, using descriptive statistics to identify trends, challenges, and best practices.*
Results. *Healthcare stakeholders selected the most relevant Sustainable Development Goals for hospitals. Sustainability is widely recognized as a priority, yet resource allocation emerges as marginal. The most frequently cited constraint for improving environmental sustainability was financial constraints (n=27/30). Indeed, some hospitals are implementing energy-efficient retrofitting, high-efficiency thermal power plants, and sustainability building certification. The adoption of Building Energy Management Systems and retrofit interventions to maximise energy efficiency suggests increasing interest in sustainability performance measurement.*
Conclusions. *Despite growing awareness, financial and regulatory support must be strengthened to facilitate hospital sustainability investments. Early integration of sustainability principles, access to public and private models and multi-stakeholder collaboration are crucial. Future research and action should foster multi-stakeholders approaches, develop sector-specific sustainability frameworks and assess the long-term impact of sustainability initiatives in healthcare.*

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Annali di Igiene : Medicina Preventiva e di Comunità (Ann Ig)
ISSN (print) 1120-9135 ISSN (online) 3035-5559

https://www.annali-igiene.it

Background

Sustainability: a challenge for healthcare facilities

Healthcare infrastructures are fundamental assets for maintaining, restoring and promoting the health of the entire population. Among these, hospitals represent the core of the healthcare delivery system, as they concentrate the most critical and specialized medical services. Indeed, hospitals are among the largest consumers of economic and environmental resources in the healthcare sector. In 2022, hospitals accounted for 36.4% of total current healthcare expenditure in the European Union (EU) (1), underscoring their significant financial impact. Similarly, their environmental footprint is considerable, as they require large amounts of energy, water, and materials to maintain operations, making sustainability a key challenge in the modernization of healthcare infrastructure (2,3).

Therefore, well-functioning socio-economic system would be inconceivable without core healthcare facilities, such as hospitals. However, hospitals are among the most energy-consuming and environmentally impactful infrastructures in modern economies (4,5). This high level of consumption is an increasing concern among healthcare stakeholders, however the resource demand remains unavoidable, since it is driven by the continuous operation of clinical services, which must remain fully functional around the clock without interruptions, to accommodate critical care and emergency situations (6,7). Furthermore, hospital complexes accommodate fragile and vulnerable individuals, who require specific and differentiated levels of comfort in terms of thermo-hygrometric conditions. Furthermore, hospitals are typically large-scale infrastructures, leading to a significant resource consumptions and consequent environmental impact. The healthcare sector, particularly in high-income countries, has a notable environmental footprint, driven by the growing demand for economic and environmental resources necessary to uphold high-quality healthcare standards. Notably, there is a direct correlation between Gross Domestic Product (GDP) growth and increased resource consumption, as economic expansion often leads to greater healthcare service demands, further intensifying the sector' burden (8,9). In 2022, the Lancet Countdown Report revealed that carbon dioxide (CO_2) emissions from the healthcare sector contribute to 5.2% of global emissions (4).

One of the recently concluded United Nations Climate Change Conferences (COP28) gave rise to a unique moment in history: 123 countries signed a declaration to "*put health at the centre of climate action*" and support the development of climate-resilient, sustainable and equitable health system (10). In line with the so-called "One Health" approach, sustainability actions to tackle climate change are strictly related to health. Climate change is one of the most important global health threats of our time, that countries around the world are seeking to address, due to its negative impact on the natural environment and on the whole humankind (4,11,12). It has been identified as *"potentially the greatest health challenge of the twenty-first century"*, as it contributes to the increase of Non-communicable Diseases (NCD's) and facilitates the spread of new infectious diseases, with considerable impacts on the healthcare sector and its infrastructures (10). In fact, by causing an increase of both recurrence and harshness of extreme weather events, climate change exerts a direct negative impact on health, provoking injury and illnesses. Rising air pollution alters the patterns of vector, food and water-borne diseases and global warming also has mediated effects on social and human systems, including malnutrition, occupational heat stress and mental illness and the risk to increase the rate of population displacement (11). The effects of global warming are particularly relevant on the most vulnerable populations, such as those with pre-existing medical conditions, the poor, children and the elderly, affecting the middle-and low-income populations as well as nations (13).

In addition to the challenges arising from the mitigation of climate change, the evolution of global healthcare models requires a profound rethinking of healthcare infrastructures as an opportunity to interpret the multiple drivers that are transforming contemporary societies at a social, economic and environmental level (14). The global challenges of our time, such as aging population, inclusive design, artificial intelligence, climate change and urbanisation, may find their synthesis and balance in the "*architectural project*", which has clear sustainable objectives both in terms of individual projects and the system level. The hospital is the social architecture that interprets the most the social instances and transformation (15). This complex social facility accompanies the great demographic, technological and epidemiological evolutions and condenses them in a key physical space, contributing to global health through the creation of healthier, more efficient and comfortable healthcare systems (2,16).

Sustainability in Healthcare: a definition

Many definitions of sustainability in healthcare can be found in the literature, including the one proposed

in 2011 by Mohrman and Shani according to whom "*sustainable healthcare is about being more efficient in preventing and minimising the impact of ill-health, which is not only dependent on health care services occurring within the facilities, but also on the improvement of the health status of the entire community*" (17). Previous definitions appear to be generic and lack cohesion in outlining what effectively are the characteristics of sustainability in a complex area such as healthcare. More recently, in the latest trends of healthcare design research field, Singh argues in the book "Planning and Designing Healthcare Facilities" (2018), that a sustainable hospital building can be broadly defined as "*a structure that enhances patient well-being and supports the healing process, while also efficiently utilizing natural resources in an environmentally respectful manner. Such a building helps reduce long-term energy consumption while simultaneously improving the health of patients and the community*" (18).

In 2020, the World Health Organization (WHO) issued a guide entitled: *"WHO guidance for climate-resilient and environmentally sustainable health care facilities"* in which environmentally sustainable health care facilities are defined as those "*facilities that improve, maintain or restore health, minimising negative impacts on the environment and exploiting opportunities to restore and improve*". Recognizing that healthcare facilities both contribute and are impacted by climate change, the document underscores the importance of integrating environmental sustainability as a core element in healthcare planning. It highlights the need to mitigate risks posed by healthcare operations, while simultaneously reducing vulnerabilities and exposures to climate-related hazards, as a major threat to Public Health (19,20).

Study Design

The rapid evolution of technological, demographic, epidemiological, environmental and social factors is driving the urgent need for greater investment in a sustainable hospital infrastructure model (21). These transformations necessitate a comprehensive, interdisciplinary approach to healthcare facility design, ensuring that future hospitals can effectively respond to emerging challenges, while satisfying contemporary clinical needs (8,22). To facilitate the collaboration and interaction between different stakeholders, and to provide guidelines for healthcare decision-makers, the Joint Research Partnership Healthcare Infrastructures (JRP HI) was established in February 2022 at Politecnico di Milano. This research platform brings together hospitals, private companies operating in the healthcare sector and public institutions involved in the definition of national and local healthcare policies. The scientific platform has been constituted with the aim to develop a new model for the Next Generation Hospital, with functional requirements and guidelines for healthcare facilities of the future. A fundamental pillar of this initiative is environmental sustainability, which has been identified as a key driver in the evolution of healthcare infrastructure. Sustainability considerations are increasingly shaping investment priorities and research and development efforts among healthcare managers, design and engineering firms, and industrial partners across the entire healthcare supply chain (19,23,24).

Research aim

This study aims to assess the level of interest, awareness, and maturity of hospitals regarding environmental sustainability and explore how sustainability principles can be effectively integrated into healthcare organizations to foster environmental responsibility across the entire supply chain. The research focuses on how healthcare key players perceive, prioritize, and implement sustainability strategies. By leveraging a national survey, the study examines the readiness of hospitals to adopt sustainability measures, their alignment with international sustainability frameworks such as United Nations (UN) Sustainable Development Goals (SDGs), and the key enablers and barriers affecting this transition. Additionally, it explores how sustainability can be effectively embedded within hospital management and decision-making processes to raise awareness and drive systemic change across the healthcare sector.

Methods

As part of the research activities conducted within the JRP HI research partnership, a national web-based survey was administered to identify the key drivers and constraints influencing innovation in healthcare facilities. The survey was conducted between November 18, 2022 and January 10, 2023, through an online questionnaire distributed to the partners of the research platform, both hospital organizations and industrial stakeholders actively engaged in the initiative at the

time. The questionnaire has been structured around four thematic areas, which where collectively defined by the research partners to guide the functional conceptualization of the Next Generation Hospital. Hospitals and industrial companies from the healthcare sector could respond to all sections of the survey, or select specific criteria to address. The study highlights the results related to the dimension of Environmental Sustainability (Table 1).

Table 1 - Dimensions investigated in the survey on Functional Design innovation for the Next Generation Hospital.

Investigated Dimensions
Logistics
Flow Management
Flexibility and Modularity
Environmental Sustainability

This dimension resulted as one of the main topics discussed during previous workshop with JRP HI partners, crucial for the contemporary debate on the strategies to be involved at all levels for both healthcare delivery organizations (e.g. hospitals, territorial healthcare centres) and companies operating in the healthcare sector. The questionnaire was designed to investigate the perception, priorities and implementation of sustainability strategies in hospital facilities. It aimed to assess the alignment of healthcare organizations with sustainability principles, the challenges and opportunities in adopting sustainable practices and the existence of measurement tools and best practices within healthcare infrastructures.

The section consisted of seven questions, employing a mix of multiple evaluation methods, ranging from multiple selection, Likert scale and binary choices and open responses to capture both quantitative and qualitative insights (Table 2).

The questionnaire was disseminated through a mailing list including healthcare managers of both public and private Italian hospitals and private companies operating in the healthcare sector, involved in the JRP HI. A preliminary data analysis was conducted using descriptive statistics to identify key influencing factors and to highlight potential innovation strategies that could be adopted by hospital management and technical staff. This analysis aimed to provide an evidence-based understanding of the current state of environmental sustainability integration within Italian healthcare facilities.

The survey was conducted via a web-based platform and targeted partners and affiliated institutions of the JRP HI research network. Out of 32 partners in total, 30 hospitals and private companies in the healthcare sector responded, resulting in a high participation rate of 94%.

Table 2 - Structure and Evaluation Methods of the Survey.

Question	**Evaluation method**
Question 1 (Q1): Selection the most important Sustainable Development Goals (SDGs) for hospital facilities.	Multiple selection (*from one to a maximum of five options, from the list of all SDGs)*
Question 2 (Q2): Assessment of the priority of sustainability for healthcare organizations	Likert scale 1-5
Question 3 (Q3): Assessment of the resources allocated for the implementation of sustainability strategies	Likert scale 1-5
Question 4 (Q4): i) existence or non-existence of a tool to measure sustainability performances. ii) The possibility to briefly describe existing tools adopted by the organization to measure the performances (open answer)	Yes/no Open answer
Question 5 (Q5): Indication of the main constraints that hinder the implementation of sustainability strategies.	Multiple selection (*from one to a maximum of three options, from a list of items proposed by the questionnaire, with the possibility of inserting other items*).
Question 6 (Q6): Indication of the main drivers that favour the implementation of sustainability strategies.	Multiple selection (*from one to a maximum of three options, from a list of items proposed by the questionnaire, with the possibility of including other items*)
Question 7 (Q7): The existence or non-existence of case studies or innovative procedures, experiences related to sustainability and its description.	Open answer

Results

The collected responses provided valuable insights, shedding light on both the breadth and complexity of the sustainability-related topics explored in the study. Regarding the sample composition, 73% of respondents represents companies operating in the healthcare supply chain, while 27% represents hospitals. This distribution ensures a diverse range of perspectives, particularly on the practical and operational challenges associated with implementing sustainability initiatives in healthcare infrastructure.

SDG relevance for healthcare organizations

Hospital management and companies in the healthcare sector were asked to identify the most impacting SDGs. The most selected SDGs among the 17 goals of the UN framework were the following:

- SDG3 "*Ensure healthy lives and promote well-being for all at all ages*" has results as the most selected (n=7/8) by hospital managers; (n=18/22) by companies in the healthcare sector.
- SDG13 "*Take urgent action to combat climate change and its impacts*" (n=3/8) by hospital managers; (n=13/22) by companies in the healthcare sector.
- SDG9 "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*" (n=3/8) by hospital managers; (n=8/22) by companies in the healthcare sector.
- SDG8 "*Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all*" (n=3/8) by hospital managers; (n=7/22) by companies in the healthcare sector.
- SDG11 "*Make inclusive cities and human settlements, safe resilient and sustainable"* (n=2/8) by hospital managers; (n=12/22) by companies in the healthcare sector.

Relevance, resources and tools for environmental sustainability

The relevance of sustainability stands with a score of 3.77 on a Likert scale from 1 to 5, with the vast

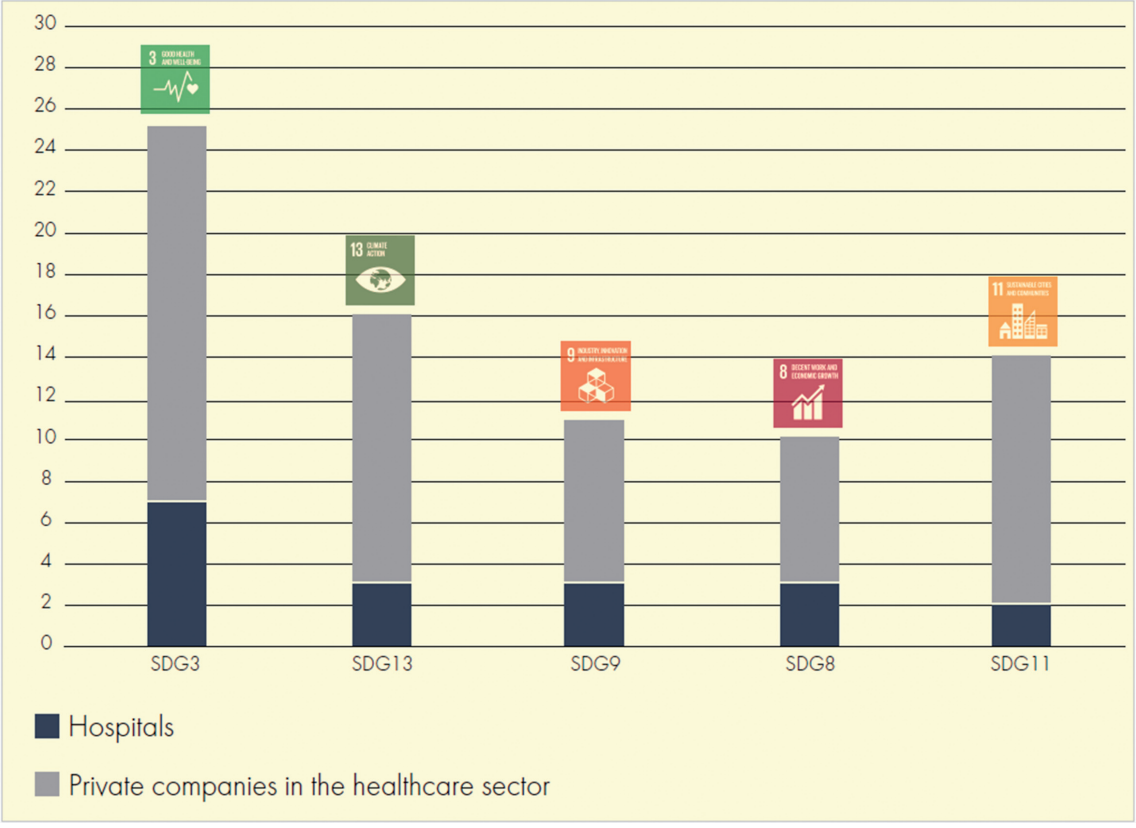

Figure 1 - Identification of the most relevant SDGs for healthcare facilities from the survey.

majority of respondent recognizing its significance for healthcare organizations. In fact, a minor share of the participants indicating scores below (n=2/30), reflect a broad consensus on the importance of sustainability in hospital infrastructure and operations.

However, in terms of resources allocation (Q3) for improving sustainability performance, the average score was significantly lower, resulting 2.60. This result highlights a discrepancy between perceived importance and actual investment in sustainability initiatives.

In response to Q4, which investigated through yes/no and open answers for clarification, the existence of environmental sustainability assessment tools in healthcare environments, respondents identified the Building Energy Management System (BEMS) and the Computerized Maintenance Management System (CMMS) as the most commonly used tools. These tools play a crucial role in enhancing sustainability performance, by enabling efficient resource management. Additionally, other monitoring instruments were reported, including energy certification systems and CO emissions tracking tools, indicating a growing awareness of performance measurement mechanisms in healthcare facilities.

Constrains, drivers and case studies

Question 5 explored the main constraints that hinder sustainability improvements in healthcare organizations. The most frequently cited constraint was the financial constraint (n=27/30). Indeed, most respondents highlighted the difficulty in securing funding for building stock renovation and organizational transformation necessary to enhance sustainability performance. In addition, healthcare organizations struggle to apply innovative strategies in day-to-day operations for sustainability improvement (n=22/30).

The architectural and physical constraints of healthcare infrastructures were reported as one of the most critical barriers (n=19/30), emphasizing the limitations imposed by existing hospital facilities, that were not originally designed with environmental sustainability principles in mind.

Additionally, to a lesser extent, organizational and management inefficiencies (n=8/30) and a shortage of adequately trained personnel (n=7/30) were identified as further obstacles, suggesting that both governance improvements and workforce capacity building are necessary to foster sustainability in healthcare settings. As regards the drivers to improve sustainability performances (Q6), respondents have reported the following factors: the introduction of innovative construction system and lower energy intensive plants (n=14/30) to reduce the environmental footprint of hospital infrastructures. An equal proportion of respondents highlighted the contribution of environmental protocols and other sustainable certifications (n=14/30). This result suggests that formal sustainability frameworks are essential for guiding hospital sustainability efforts.

In addition, respondents also acknowledged the availability of funds from the Next Generation Europe plan and National Recovery and Resilience Plan (NRRP) as a potential enabler of sustainability improvements. However, despite its strategic importance, this financial driver was selected by only 30% of respondents, a notably lower rate compared to other factors. This result suggests that, while funding opportunities exist, there may be challenges related to accessibility, awareness, or the complexity of integrating these funds into hospital sustainability projects. The findings highlight the need for both technical and financial enablers to be effectively leveraged in the transition toward sustainable healthcare infrastructures.

In the case study section (Q7), a respondent refers to the new realisation of high-efficiency thermal power plants energy efficiency (cogeneration, trigeneration and use of renewable sources). Another case study presented refers to the construction of a new hospital wing and the renovation of existing facilities, aimed at achieving Leadership in Energy and Environmental Design (LEED) certification, incorporating sustainability principles from the initial design and planning stage. Additionally, other respondents (n=2) reported retrofit initiatives, such as the installations of new energy-efficient lighting systems (relamping) and the replacement of company vehicles (renewal of company car fleet), with more sustainable alternatives to reduce the environmental impact. An additional case study was reported with reference to the Single Environmental Authorisation, related to the disposal of wastewater discharges, atmospheric emissions of pollutants, noise impact and waste treatment.

Discussion

The findings of this study highlight the critical role of sustainability in healthcare facilities transformation and the increasing importance of this topic for healthcare stakeholders, as suggested in the background findings (7,16). The study confirms

that while awareness of environmental sustainability concerns in healthcare environment is high among the stakeholders, there remains a discrepancy between its perceived importance and the level of investment in transformative sustainable practices. A key takeaway from the survey is that financial and architectural constraints remain the primary barriers to implementing sustainability strategies in hospitals. The difficulty in securing funds for renovation and technological upgrades was cited by most respondents as the key difficulty. Furthermore, the outdated building stock of existing hospitals, which were often built without taking into account environmental considerations, was identified as a major challenge. As regards the alignment with international reference, the study shows that SDGs are a crucial component for ensuring health at the global level and to reinforce the efficiency of health systems, addressing the environmental and ecological dimensions of sustainability.

The study also pointed out the adoption of sustainability assessment tools in hospital facilities. BEMS and CMMS were the most commonly used tools, allowing hospitals to monitor energy consumption, optimize resource use, and enhance operational efficiency. Additionally, some respondents reported the use of energy certification systems and CO emissions tracking tools, indicating a growing commitment to sustainability performance measurement. This preliminary analysis of the state of the art regarding the maturity level of healthcare stakeholders in addressing environmental sustainability offers valuable insights into current practices and presents case study interventions undertaken by the participating stakeholders. These include retrofitting interventions in existing hospital facilities with energy-efficient solutions, such as Light Emitting Diodes (LED) relamping and the integration of renewable energy capacity to mitigate energy consumption and procurement. Additionally, the adoption of high-efficiency thermal power plants, including cogeneration and trigeneration systems has been implemented to enhance energy performance and resource optimization. Furthermore, some hospitals are increasing interested in adopting building sustainability certifications for new projects and major renovations to ensure that sustainability principles are embedded from the initial design phase.

The sustainability of healthcare facilities will increasingly depend on a variety of factors and dimensions. These factors include energy consumption, utilization of renewable energy sources, water management and usage, waste management, ventilation and lighting efficiency, air quality, and sustainable construction materials and techniques Also, evidence-based sustainability approaches can be implemented to assess hospital facilities in this domain (25). The use of evaluation tools and certifications can be extended to improve ESG (Environment, Social, Governance) performances of the healthcare organization in line with the global SDG targets and indicators (26).

Conclusions

The survey conducted has revealed a significant gap in initiatives, budget allocation, and standardization for managing and enhancing environmental sustainability performance in healthcare infrastructure. The key findings underscore the need for strategic financial planning and investment in adaptable, modular hospital designs that facilitate energy efficiency and resource management. Despite the broad consensus on the importance of sustainability, progress remains hindered by financial constraints, architectural limitations, and operational challenges. Moreover, while strategic managers recognize the importance of reducing healthcare environmental footprint, they often lack specific operational plans and trajectories to implement sustainability plans over time.

However, technological advancements, regulatory frameworks, and collaboration between institutions and healthcare providers offer pathways for overcoming these obstacles. To accelerate the transition toward sustainable healthcare, several key actions should be prioritized. Firstly, enhancing financial accessibility with funding mechanisms, improving awareness of available financial resources to healthcare managers will be critical to support sustainability initiatives. Also, the integration of sustainability design approach and consideration from preliminary design phases is crucial. Future hospitals should adopt modular, flexible, and energy-efficient designs, enabling greater adaptability and resource optimization while enhancing long-term sustainability. Expanding the use of sustainability measurement tools could also play a role, standardizing sustainability performance metrics to enable better benchmarking and decision-making in hospital management. Finally, as outlined by the structure of the research platform, a multi-stakeholder collaboration is necessary. Increased cooperation between healthcare institutions, policymakers, and private-sector stakeholders will be essential for developing a cohesive sustainability strategy.

As global health challenges evolve and climatic changes intensifies, the role of sustainability in

healthcare will become increasingly critical. The findings of this study contribute to the ongoing debate on how to integrate sustainability into hospital operations and infrastructure and support the definition of strategic prioritization for the research platform partners. Future research should focus on developing sector-specific sustainability frameworks and expanding empirical studies to measure the long-term impact of sustainability initiatives in healthcare.

Conflict of interest statement: The Authors declare no conflict of interest.

Funding: This research received no external funding.

Acknowledgments: The authors acknowledge the support provided by the Joint Research Platform Healthcare Infrastructures (JRP HI), established at Politecnico di Milano, and its role in guiding the national debate on healthcare infrastructures.

Riassunto

La sostenibilità ambientale negli ospedali di nuova generazione: identificazione di bisogni e requisiti delle organizzazioni sanitarie e degli stakeholder del settore.

Introduzione. Gli ospedali rappresentano le infrastrutture civili a più alta intensità di risorse, con un significativo consumo di energia, acqua e materiali, e contribuiscono al 5,2% delle emissioni globali di diossido di carbonio. Nonostante la crescente consapevolezza e gli impegni internazionali, gli ospedali affrontano ostacoli finanziari, strutturali e operativi nell'attuazione di strategie di sostenibilità.

Disegno dello studio. L'indagine è volta a valutare la maturità degli stakeholder del settore sanitario rispetto al tema della sostenibilità ambientale, esplorando i principali fattori trainanti, le barriere e le strategie per integrare la sostenibilità nelle infrastrutture sanitarie.

Metodi. Una survey nazionale online è stata condotta nell'ambito della Joint Research Partnership Healthcare Infrastructures tra novembre 2022 e gennaio 2023, raccogliendo 30 risposte su 32 partner della piattaforma (tasso di partecipazione del 94%). L'indagine si concentra sulla dimensione della sostenibilità ambientale, utilizzando statistiche descrittive per identificare tendenze, criticità e best practice.

Risultati. In primo luogo, gli stakeholder hanno identificato gli obiettivi di sviluppo sostenibile più rilevanti per gli ospedali. Il vincolo maggiormente segnalato per migliorare le performance di sostenibilità ambientale riguarda le limitazioni finanziarie (n=27/30). Tuttavia, alcuni ospedali stanno implementando interventi di retrofit energetico, impianti termici ad alta efficienza e certificazioni di sostenibilità. L'adozione di Building Energy Management Systems e interventi di retrofit finalizzati a massimizzare l'efficienza energetica indicano un crescente interesse verso la gestione delle performance di sostenibilità.

Conclusioni. Nonostante la crescente consapevolezza della sostenibilità ambientale, è necessario rafforzare il supporto finanziario e normativo per agevolare gli investimenti degli ospedali. L'integrazione dei principi di sostenibilità, l'accesso ai modelli di finanziamento pubblico-privati e la collaborazione multi-stakeholder sono elementi essenziali. Le azioni e prospettive dovrebbero promuovere approcci basati sulla collaborazione tra molteplici portatori d'interesse, sviluppare modelli di sostenibilità specifici per il settore sanitario e valutare l'impatto a lungo termine.

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