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Cost-Effective Strategies for Sustainable High-Performance Buildings in Mumbai's Educational Institutes

Sahil Palande[1], Atul Munankar[2], Somdotta Dey[3]

[1]Student, S. P. Mandali's Prin. L. N. Welingkar Institute of Management Development and Research (PGDM), Mumbai, E-mail-sahil.palande@welingkar.org
[2]Student, S. P. Mandali's Prin. L. N. Welingkar Institute of Management Development and Research (PGDM), Mumbai, E-mail-atul.munankar@welingkar.org
[3]Student, S. P. Mandali's Prin. L. N. Welingkar Institute of Management Development and Research (PGDM), Mumbai, E-mail- somdotta.dey@welingkar.org

Abstract
Mumbai has had concerns regarding climate change for the past few decades. Mumbai University has over 800 HEIs affiliated with itself, and these institutes form a major contributor to the city's 23% greenhouse gas emissions from buildings. Therefore, a need to integrate high-performance building initiatives becomes essential for reducing carbon footprint and increasing operational efficiency. High-performance building initiatives focus on energy efficiency, sustainable building materials, waste reduction, and eco-friendly practices. However, limited budgets and inadequate awareness pose challenges to their implementation. This study explores the perceptions and awareness of students and staff regarding sustainability practices, using a mixed-method approach of surveys and interviews. Data revealed a positive attitude toward green initiatives, highlighting the willingness to invest in sustainable practices when adequately supported by grants and financial incentives. Case study analysis of successful international and domestic cases provides actionable strategies, such as energy-efficient retrofits, water conservation systems, and waste recycling programs, tailored to Mumbai's climate and environmental context. Findings emphasize the role of collaborative efforts involving institutional management, policymakers, corporate partners, and the government to overcome barriers and promote green initiatives. The research identifies gaps in current practices and proposes a framework for fostering sustainable transitions in HEIs, ultimately contributing to the global goal of environmental sustainability while enhancing educational standards.

Keywords
Sustainability, High-Performance Buildings (HPBs), Green University, Higher Education Institutions, Energy Efficiency.

Introduction
India has over 58,000 higher educational institutes (HEIs), making it the world's second-largest education system. Out of these, approximately 800 HEIs are affiliated with Mumbai University (NAAC, 2021). According to a report published by MCGM (2022), commercial facilities, including higher education institutes, are responsible for 23% of GHG emissions and are capable of generating 71 MW of energy through rooftop solar facilities. Buildings hinder the escape of radiations of higher wavelengths, causing a rise in temperature during the night (Srivastava et al., 2016). This phenomenon is defined as the heat-island effect, where temperature remains higher in urban areas in comparison to its surroundings (Ghorbany et al., 2024). Main reasons for this effect

are the use of artificial surfaces used for construction that retain heat, reduced forest cover, and emissions due to human activities (Ghorbany et al., 2024; Srivastava et al., 2016). The idea of high-performance building has developed in view of rising environmental and socio-economic problems of the society (Tokbaevich et al., 2024). Due to recent advancements in research and technology, green buildings, also called high-performance buildings, passive buildings, and zero energy consumption buildings, have become a focal point to address this issue (Cheng, 2021; Tokbaevich et al., 2024).

The concept of high-performance building (HPB) or green deals with maximizing energy efficiency and quality of internal environment by optimizing building design by use of advanced technologies and construction materials (Tian, 2023). Conventional building designs sometimes overlook the long-term effects on the environment, which raises energy and operating expenses (Abeywardhana, 2024). Thus, decreasing the harmful effects of buildings has become a priority for stakeholders like governments, businesses, and common people around the globe and helps achieve sustainable goals (Mao et al., 2024). Universities in recent times correlate to small cities, and it is possible, if done correctly, to contribute to achieving sustainable goals in the education sector (Fissi et al., 2021).

The higher education sector is now trying to incorporate sustainability, which has posed a great challenge for academicians, students, management, and policymakers (Yuan et al., 2013; Marques et al., 2019). Green buildings aim to decrease energy consumption, reduce waste, and improve the indoor environment by using LED lighting, efficient heating, ventilation, aeration, and cooling (HVAC) systems, and efficient waste disposal (Tokbaevich et al., 2024). These features can be incorporated in HEI to convert existing structures into high-performance HEI that can contribute to lowering climate change impact and increase productivity by around 25% (Weerasinghe et al., 2021). Given the high cost of these facilities and the financial constraints faced by higher educational institutes (Education Times, 2024), it is crucial to develop cost-effective strategies to boost long-term savings.

Review of literature

High-performance buildings (HPBs), according to the Institute of Building Sciences (2008), are buildings that focus on environmental, human, economic, and societal development aspects and implement critical constructional and operational changes in the design of such buildings. The main points on which HPB or green buildings are assessed are energy (Yudelson, 2008), water, materials, indoor environment, health and wellbeing (Day & Gunderson, 2015), transport, management, and innovation (Siew Goh & Cheng Siew, 2023). These initiatives are an integral part of successful high-performance buildings and can be incorporated into any type of building. Researchers have extended this concept to sustainable and green universities.

Sustainable University and Campuses

Fissi et al. (2021) put forth the definition of a sustainable university as an educational institution that works on the principles of green economics, social and environmentally friendly practices. These institutions fulfill the tasks of teaching, research, and community engagement in a manner that helps society embrace a sustainable lifestyle. The idea of green and smart university campuses is receiving attention as HEIs sense the requirement of investing in environmentally friendly

initiatives and minimizing impact on the environment (Al-Dmour, 2023). Smith and Johnson (2022) hail universities as forerunners in addressing problems related to climate change. As universities experiment with the implementation of smart-sustainable initiatives that achieve waste reduction, energy efficiency (Filho et al., 2019), sustainable transportation, and management, they plan towards the creation of campuses that are environmentally mindful and future-ready (Pupiales-Chuquin et al., 2022). However, Bui et al. (2023) reported a significant gap in understanding of complete sustainable university representation. The perception and backing of management and stakeholders have also been mapped inadequately (Thondhlana & Nkosi, 2024).

Characteristics of High-Performance Buildings

Energy Efficiency: HPB makes use of maximum daylight to minimize excessive use of energy and increased interior lighting (Heerwagen, 2000). Green buildings incorporate techniques that decrease energy consumption by adopting LED lighting, energy-efficient windows, and efficient HVAC systems (Tokbaevich et al., 2024). Inclusion of these methods enhances the well-being of users and leads to a significant reduction in energy bills and carbon output from the buildings. (Heerwagen, 2000; Tokbaevich et al., 2024).

Sustainable Materials: Green structures include environmentally sustainable and durable materials. Green buildings employ sustainable materials that decrease impact on the environment and improve the quality of indoor air (Tokbaevich et al., 2024). Heerwagen (2000) reported that these materials should have low toxicity that does not contribute to pollution of land, air, and water.

Renewable Energy Sources: Renewable energy sources, including solar panels and geothermal systems, are included in many green buildings. Indoor greenhouse gas emissions and reliance on fossil fuels are decreased via on-site renewable energy production (Tokbaevich et al., 2024).

Impact on Environment: By using materials causing lower pollution towards the environment, green buildings retain the quality of internal air and employ proper systems for ventilation and natural lighting. These measures contribute towards enhancing the comfort and well-being of occupants (Tokbaevich et al., 2024). Heerwagen (2000) emphasized increased airflow because of advanced and mechanical ventilating systems that caused higher barriers between residents and airborne contaminants. Advanced HVAC systems resist the growth of harmful pathogens from the air affecting the health of occupants. Moreover, the addition of indoor plants proves to be beneficial for psychological well-being and quality of internal air.

Waste reduction and recycling: HPBs aim to reduce wastage of natural resources and during their entire lifecycle. Initiatives such as the use of eco-friendly materials, recyclable and biodegradable resources that decrease the carbon footprint of the structure and the waste contributing towards landfill are helpful towards this feature (Tokbaevich et al., 2024).

Cost Barriers in High Performance Buildings

Kats (2006) surveyed 30 schools in the United States that implemented green methodology in the design of the structure and reported that these schools had 2% more cost to operate than regular schools and cost premiums to be in the range of 0-18%. Shrestha et al. (2012) put forward a

contrasting analysis where construction cost per square meter of green building was significantly higher than its counterpart, and an increase of 46% in total cost was reported. Moreover, costs related to investments in the procurement of scarce construction resources affected developers (Simcoe and Toffel, 2014). Studies done by Sabapathy et. al. (2010) indicated fixed charges associated with LEED-certified buildings lead to energy cost savings of 8.5% even if the energy savings are 34% on average.

Perception and Awareness regarding Green Buildings

Understanding perceptions and current awareness of sustainable practices of university students is crucial for decision-makers, as these form views of a major stakeholder. Also, it would allow better engagement of students in these initiatives if they are facilitated to be proactive. (Newport et al., 2003; Nicolaides, 2006). Too & Bajracharya (2015) put forth the idea for increasing community engagement in sustainability through their 6-P framework. This framework included parameters like psychological, physical, personal, price, public perception, and policies. Nejati & Nejati (2013) gave parameters such as community outreach, sustainability commitment and monitoring, land use and planning, and waste and energy as important for assessing students' perceptions. In another study, Tuncer (2008) reported differences in perceptions among male and female students regarding sustainability. Emanuel & Adams (2011), in their study, reported the commitment of students towards these initiatives as a major roadblock. A study done by Wright & Horst (2013) on faculty members revealed that financial barriers and heavy dependency on administration, government, and student bodies significantly retard sustainable transformation. Kagawa (2007) reported students perceived sustainability singularly with the environment and ignored the financial, economic, and social aspects. A study by Jones et al. (2013) indicated social circles and trust in institutions are important drivers for sustainable initiatives.

Case studies about HPB

Torcellini et al. (2006) examined the Adam Joseph Center for Environmental Studies at Oberlin College, located in Oberlin, Ohio. The center consists of four classrooms, an atrium, a kitchenette, and an auditorium. This building includes features such as daylighting, natural ventilation, massive structures to stockpile passive solar energy, a heat pump system, an efficient energy management system, and a wastewater processing plant. The energy use of this center is less than half of the average educational building in the Midwestern region.

Figure 1: Adam Joseph Center for Environmental Studies at Oberlin College

Another successful example of green building in the educational domain is Oasis School in

Kyrgyzstan. The energy needs are supplied through an amalgamation of solar panels and wind turbines installed in the school premises. The building design has also incorporated passive strategies such as natural ventilation, daylight optimization, and rainwater harvesting to reduce excessive water consumption (Tokbaevich et al., 2024).

Research Gap

Literature exposes inadequate studies on high-performance buildings and sustainable initiatives in HEIs in India and especially in Mumbai. There are studies that talk about these HPBs all around the world, but the data regarding the same is scarce in the Indian context. In the context of awareness and perceptions regarding HPBs in college students of Mumbai, this study is relevant. This study aims to address this gap by raising awareness among stakeholders and suggesting strategies that can be employed in Mumbai's HEI.

Objectives

1. To understand perception of students in higher educational institutes about their perceptions regarding sustainability and high-performance buildings.
2. To suggest cost effective strategies for sustainable high-performance buildings that can be implemented in HEIs in Mumbai.
3. To raise awareness about high-performance buildings that can benefit various stakeholders associated with education sector.

Research Methodology

The research methodology framework is both exploratory and descriptive. This study aimed to analyze the perceptions and awareness of stakeholders towards the concept of HPBs. Also, a descriptive analysis of various methods employed across the globe for sustainable practices was aimed for. The research was conducted using both qualitative and quantitative methods. Secondary data was collected using an extensive literature review from published data on databases like EBSCOhost, Science Direct, and Google Scholar. Based on an extensive literature review, gaps associated with the research question were identified. To achieve answers for identified research gaps, a comprehensive questionnaire and interview model was devised to gain primary data. The questionnaire survey was directed using Google Forms, a free-to-use online survey platform, in a convenience sampling fashion. These forms were circulated using social media platforms such as WhatsApp, Instagram, etc. 12 out of the 18 questions asked in the survey were either based on a 5-point Likert scale or were converted to a 5-point Likert scale during data cleaning. Along with the questionnaire survey, questions were formulated for an interview with faculty and staff members. The focus of the interview was on existing facilities, intervention of technology, engagement, and challenges associated with sustainability initiatives. Post 30 responses, reliability testing of the survey instrument was performed by the Cronbach's Alpha method using IBM's SPSS 30.0.0.0 (172) statistical software. Cronbach's alpha value was 0.897, and thus the validity of the questionnaire was confirmed.

Following Hypothesis were Framed for the Study

H0A: There is no significant relationship between grants provided by government and financial priorities towards sustainability initiatives.

H0B: There is no significant relationship between decision of staying at campus concerns and engagement in sustainable initiatives.
H0C: There is no significant relationship between grants provided by government and financial priorities towards academic courses related to sustainability.

Data Analysis & Interpretation

Data analysis of responses collected from 148 participants identified key patterns regarding awareness, perceptions, and key factors associated with sustainability in the HEIs in and around Mumbai. The analysis of the data collected is mentioned below:

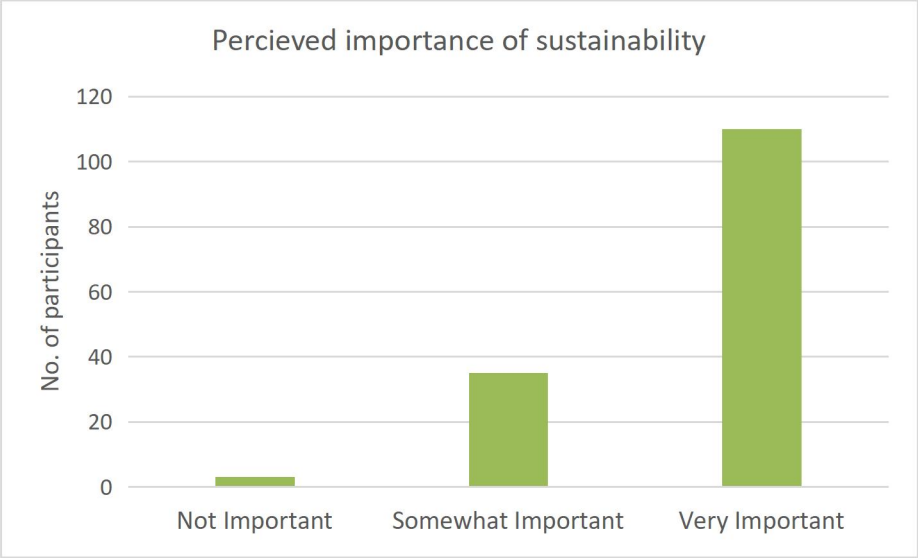

Figure 2: Perceived Importance of Sustainability

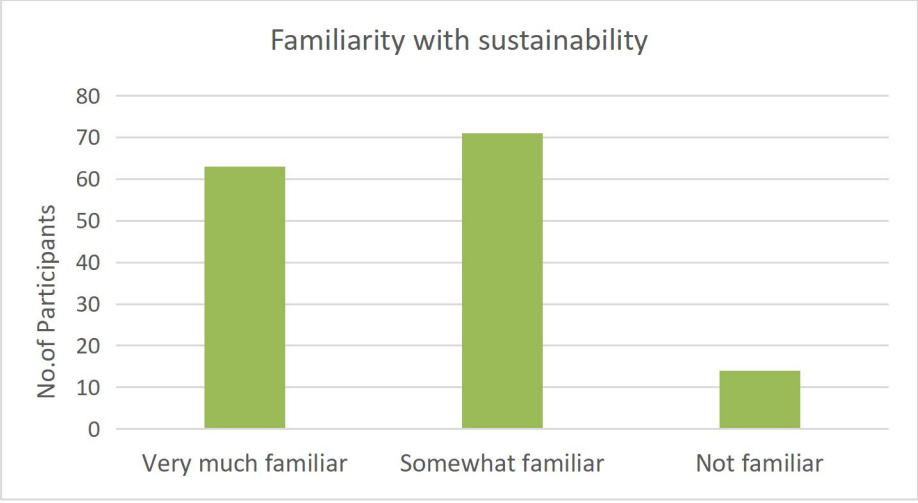

Figure 3: Perceived familiarity with sustainability concepts

Figures 2 and 3 show the importance and familiarity of sustainability among the participants. According to the statistics, participants are clearly aware of the concepts associated with and the importance of sustainable initiatives. Figure 4 depicts the perception of participants about costs

associated with these initiatives. According to analysis, almost all participants were in favor of the implementation of initiatives even though the expenses associated are high.

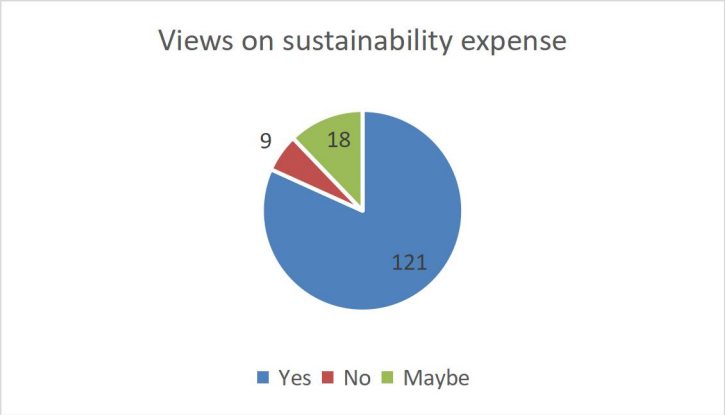

Figure 4: Perception on sustainability as a worthy expense

Table 1 shows the number of faculty participants and the existing sustainable practices identified by them in their institutions. This implies awareness of faculty participants is in significant number, and initiatives set up by the institution are well recognized.

Table 1: Faculty responses regarding existing practices

Existing Practices	No of responders
LED lighting	22
Paperless institution	18
No Plastic cutlery	11
Biogas	5
Vertical farming	4

A structured questionnaire was designed on 5-point Likert Scale (1 representing highly disagree and 5 representing highly agree). Cronbach's Alpha Value was (0.897) significantly reliable.

Table 2: Cronbach's Alpha

Reliability Statistics	
Cronbach's Alpha	No. of Items
0.897	20

Hypothesis testing was performed using the Chi-Square Test, and findings are mentioned in Table 3. It was found that there is a significant relationship between grants provided by the government and financial priorities towards sustainability initiatives. There is a significant relationship between the decision to stay at campus concerns and engagement in sustainable initiatives.

Table 3: Chi-Square Test

Hypotheses	No. of Valid Cases	Pearson Chi-Square Value	df	Asymptotic Significance (2- sided)
H0A	148	70.186[a]	9	<0.001
H0B	148	43.230[a]	4	<0.001

From table 3, it is evident that the p-value (<0.01) for all three null hypotheses is less than the alpha value (0.05). Therefore, significant relationships exist between the above-stated factors, and the null hypothesis can be reasonably rejected, while the alternate hypothesis is accepted.
Table 4 shows the values for Pearson's correlation coefficients. Pearson correlation reflected a moderate positive relationship between government grants and institutions setting up courses related to sustainability, according to participants.

Table 4: Pearson's Correlation

Variables	Pearson's Correlation	Sig. (2-Tailed)
Grants provided by government and financial priorities towards academic course related to sustainability	0.768	<0.001

Findings

The findings from survey data revealed critical relations between attitudes, perceptions, and awareness of responders towards sustainability. Responders who valued sustainability were more likely to understand its concepts and believed in the success of these practices. These responders were thus more likely to actively engage in activities related to sustainability and would choose to continue in the institution. The data showed that increased familiarity encouraged confidence, involvement in sustainability, and a higher willingness to allocate a portion of tuition fees. This also positively affects decision-making regarding valuing sustainability practices in their institutions. Data analysis further showed that responders felt an increase in engagement of stakeholders and efficient allocation of funds are done by institutes that implement sustainable practices. Increased participation also correlated with increased willingness to invest in these initiatives. Responders felt that the institute showed strategic budget allocation balancing sustainability initiatives along with academic, infrastructural, and institutional aspirations. These strategies, when implemented, increased the value of the institution as per respondents. According to respondents, government grants and private funding would help achieve sustainability goals faster and more efficiently in a budget-crunched university setting. The findings emphasize the importance of raising awareness and increasing interaction to improve sustainable behavior attitudes. Optimizing resource allocation and streamlining programs would boost institutions.

Faculty observations revealed significant administrative issues. Incentives and habits can boost engagement, but financial and communication limits limit this. The ideas suggest integrating training, certification, and lectures to smoothly implement sustainability measures.

Strategy Implementation

Data showed that waste recycling, energy reduction, environmental preservation, and awareness are the main sustainability strategies. Retrofitting structures using these techniques is global. Technology integration in modern buildings can be budgeted. Mumbai's higher education institutions can use these strategies from prestigious global institutions.

1. **Waste segregation and recycling:** This strategy is simple, cost-effective, and widely adopted across institutions. Aleixo et al. (2018) found that about 51% of Portuguese universities had fully implemented waste separation and recycling for paper, plastic, metal, oils, and batteries. In India, institutes like MGM and Terna have compost pits for wet waste, while Ruia College has a biogas plant, though its operation is under review. Monash University's 'Bin There, Done That' initiative replaced individual bins with desktop and paper recycling boxes to boost recycling efforts (Monash University, 2012; Too & Bajracharya, 2015).
2. **Energy Conservation:** High-performance buildings focus on energy conservation and, while costlier than waste recycling, offer long-term benefits. Retrofitting energy-saving measures is challenging for Indian HEIs due to financial constraints. However, passive design strategies—like smaller, well-oriented windows and reflective materials for walls and roofs—can reduce heat gain and improve ventilation (Albatayneh et al., 2018; Falzon et al., 2023). Aleixo et al. (2018) noted that 18.9% of Portuguese HEIs have adopted energy-efficient systems like solar panels and LED lighting. Cornell University's 'Lights Off, Cornell' initiative, driven by student volunteers, saved $60,000 annually (Cornell University, 2008; Too & Bajracharya, 2015). In Mumbai, institutions like R.A. Podar College and Welingkar Institute have implemented or are adopting similar measures.
3. **Water Conservation:** Conservation and judicial use of water resources become a highlighting factor for a sustainable HEI. High-performance buildings have water conservation and treatment facilities present on campus. However, keeping in mind the expenses associated with it, budget-constrained HEIs must look forward to minimal and judicious use of this valuable resource. Notable colleges within the Mumbai region have set up rainwater harvesting systems on their campuses. International authors have reported universities are willing to implement water conservation facilities as per their own capacity.

Significant cost-effective sustainability initiatives pertinent to higher education institutions in India, especially in Mumbai, include the establishment of vertical gardens for organic cultivation, the creation of greenhouses, the promotion of ecological and eco-friendly brands on campus, the implementation of sustainable transportation and electric vehicles, the utilization of eco-friendly construction materials for future projects, and the enhancement of biodiversity within and surrounding the campus (Aleixo et al., 2018).

Emerging trends encompass the introduction of curriculum focused on sustainability and climate change in educational institutions. These courses aim to enhance awareness and emphasize the integration of ecological, social, and economic factors into corporate initiatives. The program encompasses courses on ESG business strategies, environmental law, sustainable finance, and data analytics for business optimization. Institutes have begun establishing committees and teams to oversee and enhance current sustainable efforts. This seeks to enhance general involvement

and individual accountability for a sustainable, high-performance campus.

Managerial Implications

The findings from present study affect the following primary stakeholders and have implications as stated: 1. For Management and Administrators, the high level of awareness among students underscores the necessity of implementing high-performance building initiatives, as student fees cannot be the sole source of funding for them. 2. Policymakers and Government bodies must support educational institutions in carrying out HPB initiatives by providing incentives and grants. 3. Corporate organizations through their institutional partnerships and CSR activities, help education sector achieve sustainability and build a positive reputation for themselves as well as HEIs. 4. Banks and financial institutions can market specialized financing schemes for institutions willing to incorporate HPB practices. 5. Multinational corporations can help educational institutes with their technology and best practices, which would assist corporations with real-time data and equip educational institutes with world-class technology.

Conclusion

This study explored the potential of implementing cost-effective strategies for sustainable high-performance buildings (HPBs) in Mumbai's higher educational institutions (HEIs). The findings reveal that while there is significant awareness and willingness among stakeholders—especially students and faculty—several financial and administrative challenges continue to hinder the widespread adoption of sustainable practices. Nonetheless, the research presents a positive outlook, emphasizing that practical, low-cost solutions and collaborative support can accelerate the shift toward greener campuses.

To promote the adoption of HPBs in Mumbai's HEIs, the following actionable takeaways are recommended:

- **Leverage Government Grants and CSR Funding**: Institutions must actively seek financial assistance through government sustainability schemes and corporate CSR collaborations. These can reduce the financial burden and enable large-scale retrofitting and infrastructure improvements.
- **Implement Low-Cost, High-Impact Measures**: Start with cost-effective solutions such as LED lighting, waste segregation and composting, rainwater harvesting, and paperless systems. These initiatives are easy to implement, raise visibility, and build early momentum.
- **Foster Student Engagement and Curriculum Integration**: Introducing sustainability-focused academic courses and extracurricular activities can strengthen awareness and create a culture of accountability and environmental stewardship on campus.
- **Adopt Phased Infrastructure Upgrades**: Retrofitting buildings with energy-efficient windows, HVAC systems, and water-saving devices can be done in phases to manage costs while improving performance.
- **Establish Dedicated Green Committees**: Creating task forces or sustainability cells within HEIs can help monitor, plan, and evaluate green initiatives, ensuring continuity and performance tracking.
- **Collaborate with Industry and Knowledge Partners**: Partnering with environmental organizations and technical experts can help institutions access best practices, training, and innovative technologies suited to their needs and budgets.
- **Encourage Transparent Reporting**: Institutions should document and publish their

sustainability practices and progress annually to build stakeholder trust and attract funding.
In conclusion, sustainable high-performance buildings are not just environmentally beneficial but also vital for enhancing institutional reputation and student satisfaction. With the right mix of awareness, financial planning, and collaborative efforts, Mumbai's HEIs can become role models for green campuses across India.

Limitations

This study, while insightful in exploring cost-effective strategies for sustainable high-performance buildings (HPBs) in Mumbai's higher educational institutions (HEIs), is subject to several limitations that may affect the generalizability and depth of its findings. Firstly, the research was geographically limited to institutions within the Mumbai metropolitan area. While this focus allowed for context-specific insights, it restricts the applicability of the findings to other regions in India, where environmental conditions, policy frameworks, and infrastructural capacities may differ significantly.
Secondly, the sample size and diversity present notable constraints. The survey was conducted using a convenience sampling method and gathered 148 responses through online platforms such as WhatsApp and Instagram. As a result, the sample may not accurately represent the broader demographic of students and faculty across Mumbai's extensive network of HEIs. Furthermore, there was limited differentiation between types of institutions—such as public versus private, large versus small—which could influence perceptions and implementation feasibility of sustainability practices.
Time constraints also posed a significant limitation. The research was carried out within a relatively short time frame, which curtailed the ability to conduct more comprehensive interviews, extended observational studies, or track changes in attitudes and initiatives over time. This restricted timeline limited the study to a cross-sectional analysis, thereby missing potential seasonal or long-term trends in sustainability adoption.
Another important limitation was the lack of access to institutional documentation. Due to confidentiality and administrative hurdles, the research team was unable to examine internal policy documents, financial records, or operational reports that could have provided a clearer picture of the actual investment and cost-benefit structures involved in HPB initiatives. Consequently, financial evaluations were largely based on secondary literature rather than primary institutional data.
Lastly, technological and resource limitations influenced the depth of data analysis. The study relied on freely available digital tools, limiting the use of more advanced statistical or modeling techniques that could have enriched the research outcomes. These constraints highlight the need for future studies with expanded scope, longer durations, and enhanced access to institutional and financial data.

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