Agricultural & Rural Studies

Article

Quantification of Bioclimatic Performance of Rural Coastal Low-Cost Dwellings in the Sundarbans

Mahadev Bera [1], Pranab Kumar Nag [1] and Sumanta Das [1,2,*]

[1] School of Environment and Disaster Management, Ramakrishna Mission Vivekananda Educational and Research Institute, Kolkata 700103, India; beramahadev1990@gmail.com (M.B.); pranabnag@yahoo.com (P.K.N.)
[2] School of Agriculture and Food Sustainability, The University of Queensland, St Lucia, Queensland 4072, Australia
* Correspondence: sumanta.das@uq.net.au

Abstract: As we are aware that climate change poses a significant threat to environmental quality, human health, and well-being, etc., it is important to mitigate the environmental adverse impacts on human health. To do this, a necessary step forward is a bioclimatic analysis that includes a quantitative understanding of eco-human-energy friendliness. The study evaluates the environmental performance of low-cost coastal dwellings by analyzing bioclimatic components. Primary data was collected from field investigation and the perception response of 1332 dwellers from the selected blocks of coastal Sundarban region, West Bengal including remote rural, rural, and semi-urban areas was recorded. The statistical analysis indicated the upper 95% confidence limit for each subgroup and a normalization of the upper confidence limit with a unity score of 10 for each subset of parameters. The total score of the five categories of bioclimatic components was rounded to 150. A comprehensive evaluation of bioclimatic aspects of low-cost dwellings and scoring of features (design strategies, indoor environmental quality, thermal comfort, and energy efficiency) significantly yielded a quantitative rating of the performance of a rural built environment. Overall, this study successfully quantified the evaluation of the bioclimatic performance of low-cost coastal rural dwellings, which may be useful to develop strategies or building codes for the passive design of dwellings in the coastal, rural areas of India.

Keywords: bioclimatic quantification; environmental quality; rural and semi-urban settings; low-cost coastal dwellings; scoring criteria

Citation: Bera, M.; Nag, P. K.; Das, S. Quantification of Bioclimatic Performance of Rural Coastal Low-Cost Dwellings in the Sundarbans. *Agricultural & Rural Studies,* 2023, *1,* 0015. *https://doi.org/10.59978/ar01030015*

Received: 27 October 2023
Revised: 11 November 2023
Accepted: 18 November 2023
Published: 22 November 2023

1. Introduction

Buildings and all kinds of built environments contribute substantially to greenhouse gas (GHG) emissions, energy consumption (Li et al., 2019), and resource consumption, causing environmental changes and global warming (Balasbaneh & Bin 2017, 2018). Worldwide, greenhouse gases, i.e., Methane (CH_4), Carbon dioxide (CO_2), and Nitrous oxide (N_2O) continued to increase with the consequent rise in the global mean temperature by about 1.2 ± 0.1°C above the baseline 1850–1900, concerning the preindustrial level estimate (World Meteorological Organization [WMO], 2021). Rural India represents nearly 2/3rd of its total population, and the scenario predominates with low-cost dwellings (mud houses and huts). The rural populace largely depends on conventional energy sources like wood, animal dung, and agricultural residues for household chores, with scanty electricity consumption for lighting systems and other requirements (Misra, 2023; Tiwari, 2023). Low-cost dwellings carry many environmental concerns, including CO_2 and other GHG emissions from burning fuels (firewood, cow dung cakes), congested room structures, and cattle sheds. To reduce emissions, it is necessary to improve dwelling characteristics, eco-friendliness, human-friendliness, and energy-friendliness (Bera & Nag, 2022; Henderson et al., 2020). These may help minimize the adverse impacts on the environment and improve human health, comfort, safety, and enhance energy efficiency (Nag, 2019; Zr & Mochtar, 2013). Research evidence (Bal & Matzarakis, 2022; Bazzato et al., 2021; Bera & Nag, 2021; Bera & Nag, 2022; Bhamare et al., 2020; Liu et al., 2020; Mohammadi et al., 2018; Subhashini & Thirumaran, 2018; Watson, 2020) are overwhelming to elucidate effectiveness bioclimatic concepts in building and landscape designs and human comfort. Appropriate design intervention makes buildings comfortable with a due understanding of the regional climate and implementing passive design practices, such as natural ventilation, day lighting, passive heating and cooling, and using suitable local building materials for thermal storage (Attia et al., 2019; Loftness, 2020; Semahi et al., 2019; Zahiri & Altan, 2020; Zhen et al., 2016).

Attia et al., (2019) developed a bioclimatic analysis tool to identify proper bioclimatic design strategies for hot and humid climatic zones based on temperature and humidity levels. In addition, the identification of suitable passive design strategies in the specific climatic zone is based on temperature, relative humidity, wind speed, and rainfall (Hwang & Chen, 2022; Putra et al., 2022). Furthermore, the bioclimatic design strategies influence the building's environmental performance such as improving indoor thermal comfort, indoor environmental quality, and energy efficiency (Aghimien et al., 2022; Chandel et al., 2016). Few studies highlighted the various tools for evaluating the bioclimatic design strategies in specific climatic regions such as Givoni and Olgyay bioclimatic charts as well as Mahoney tables and ASHRAE standard 55 (Tamaskani Esfehankalateh et al., 2022). Bera and Nag (2022) highlighted the assessment of the bioclimatic design of low-cost rural dwellings based on the surrounding environment, indoor environment quality, residential health, energy consumption, building design and materials use, and building innovation. Table 1 shows a summary of the quantification of the bioclimatic performance of the buildings based on various parameters across different regions.

Table 1. Studies on the assessment/identification of bioclimatic design strategies of the built environment in different regions.

Study description	Research aim	Parameters used	Regions	References
Identification of bioclimatic design of low-cost rural dwellings.	To identify the passive design strategies to achieve the maximum thermal comfort and energy efficiency in the buildings.	Site and location; energy consumption; health and safety; building materials and innovation.	India	(Bera & Nag, 2022)
Assessment of bioclimatic design strategies based on Mahoney table in Esfahak village.	To investigate the possible relationship between climatic characteristics and the built environment of Esfahak, a village located in the hot desert region of Iran.	Use of Mahoney table based on different climatic parameters such as Temperature, Relative humidity, Rainfall	Hot desert region, Iran	(Hosseini, 2022)
The affordability of energy determines the sustainability of building-integrated bioclimatic design solutions.	This study investigates how climate factors and energy affordability levels relate to the use of bioclimatic design techniques.	Climatic conditions, gross domestic products, and electricity prices Use of simulation tools- *EnergyPlus, SketchUp, Meteonorm*	hot climates (Doha and Timbuktu)	(Elaouzy & El Fadar, 2023)
Identify the architectural design strategies for the dwellings of low-income people under bioclimatic criteria in Monte Sinahí, at Guayaquil.	To find out the appropriate bioclimatic design strategies for low-cost dwellings of Monte Sinahí.	Architectural morphology, urban form, building elements, and solar and wind flow control devices	Monte Sinahí, Guayaquil	(Forero et al., 2020)
Assessment and identification of bioclimatic architectural strategies for the building design of the tropical climatic zone.	To identify and evaluate the proper bioclimatic design strategies based on the guidelines proposed by Givony, and Olgyay, among others.	Use of dynamic simulation software Design-Builder to evaluate the building's passive strategies based on operative temperature, relative humidity, PMV, PPD, and discomfort hours.	Tropical climatic region of Panama	(Austin et al., 2020)
Assessment of the cooling potential of different passive design strategies using the bioclimatic aspects.	To develop an analysis tool for the evaluation of the cooling potential of different passive design strategies for different climatic zones of India.	Bioclimatic chart	18 cities of India of different climatic zones such as hot-dry, hot-humid, temperate, cold, and composite	(Bhamare et al., 2020)

Relevance exists in adopting the concept of bioclimate to building environmental performance rating systems. The bioclimatic strategies include the optimum use of natural energy sources, reducing the need for artificial sources of energy, and promoting natural ventilation to avoid the need for air conditioning for cooling (Elaouzy & El Fadar, 2023; Xhexhi, 2023). In addition, bioclimatic design strategies are a crucial architectural approach to improve indoor thermal comfort, and energy efficiency, and reduce buildings' carbon footprint (Bera & Nag, 2021; Elaouzy & El Fadar, 2022; Gupta et al., 2023). Various national and international green building rating systems (e.g., BREEAM, LEED, HQE, DGNB, CASBEE, Green Globes, SBTool, and other national schemes) apply to different built environments, including residential settings (Nag, 2019; Pontes et al., 2022). Depending on the criteria and assessment maturity, the performance rating schemes have their relative presence in building accreditation across the countries. The national and international building rating system depends on different criteria, such as site and location, health and safety, energy efficiency, indoor environmental quality, water efficiency, building materials, innovation like rainwater harvesting, use of green energy, etc. (Assefa et al., 2022; Braulio-Gonzalo et al., 2022; Menna et al., 2022).

Furthermore, no national or international organization has yet published any guidelines criteria, and ratings to evaluate the building environmental performance of low-cost rural dwellings. Scope remains in exploiting the rating systems for evaluating the environmental performance of low-cost dwellings in rural coastal settings. Dwellings in coastal regions of eastern India are tornado and flood-prone, bringing devastation every consecutive year. The present field-based study evaluated indoor environmental quality, thermal comfort, energy efficiency, and passive designs of the low-cost coastal dwellings of the stated regions.

The study aims to develop a comprehensive assessment of the environmental/bioclimatic performance of coastal, rural low-cost settings concerning national and international rating systems. The study included different parameters associated with building environmental performance rating systems to assess the bioclimatic and environmental performances of coastal and rural seaside dwellings. The components are (a) site and location, (b) energy consumption and efficiency, (c) health and safety, (d) building materials, and (e) building innovation in indoor and outdoor environments. Based on the above parameters, the study focused on standardized scoring and assessment of rural settings of the dwellings in the aspects of bioclimatic performance. This is a maiden attempt at the quantification of rural coastal dwellings from the bioclimatic perspective.

2. Materials and Methods

2.1. Site Selection and Study Area

The study focuses on the quantification of the bioclimatic performance of low-cost rural coastal dwellings of Sundarban. Primarily, South 24 Parganas district was selected for the study and considered four coastal blocks such as Patharpratima (21.7941°N, 88.3555°E), Kakdwip (21° 52' 59.88" N, 88° 10' 59.88" E), Sagar (21°39' 10" N, 88°04' 31" E) and Mathurapur-1 (22° 07' 13" N, 88° 23' 39" E) (Figure 1). Approximately 10 million people live in the study area, which is dispersed over 29 blocks with isolated rural, rural, and semi-urban environments. Of the country, mangrove cover makes up around 42% of this region. The four village blocks included in the study all have mostly hot and humid climates. Every year, temperatures are measured to be as high as 40°C and as low as 10°C. In the region, the monsoon season which includes mid-June to mid-September, receives around 75% of the annual rainfall, or about 140 cm on average (Bera & Nag, 2022). A majority of the rural populations in this region reside in low-cost dwellings made up of earthen materials, such as mud, wood, mud mixed with straw, etc. (Figure 2).

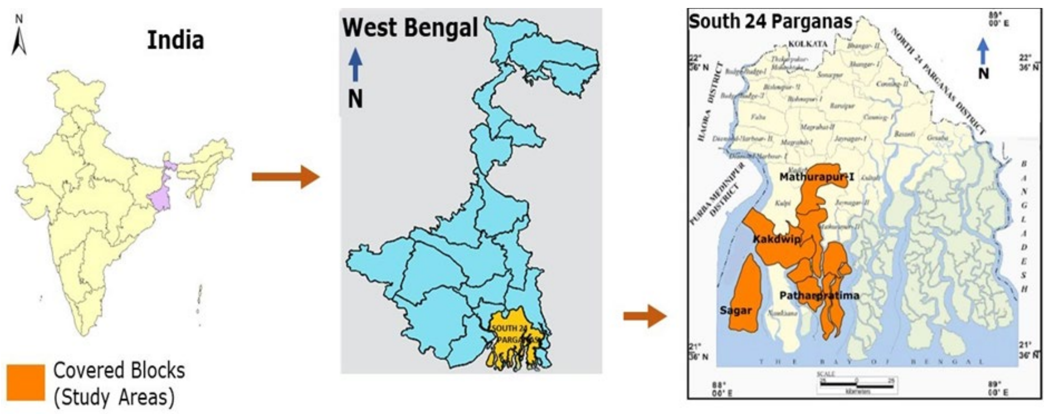

Figure 1. Location map of the study area.

Figure 2. Low-cost dwellings of the rural, coastal Sunderbans region in India.

2.2. Field Survey and Primary Data Collection

The bioclimatic components of remote rural, rural, and semi-urban community dwellings from 97 checkpoints of the selected blocks (Patharpratima, Kakdwip, Sagar, Mathurapur-I) under coastal households setting in the Sundarban region of West Bengal state in Eastern India were evaluated using a field-based questionnaire survey from 1332 individuals across the year. The questionnaire was designed meticulously to compare dwellers' perceptions across seasons and study sites (remote rural, rural, and semi-urban settings). Random sampling was followed to collect the primary questionnaire survey data from a diversified, widespread location of 97 checkpoints within the study area. The selection of parameters for assessing the environmental performance of rural houses mainly aligns with internationally recognized building rating systems, including IGBC, LEED, BREEAM, and national building codes (GRIHA, India). The questionnaire survey sheet consists (Table S1) of information about the surrounding environment, the design of the built environment, energy consumption, health and safety (including indoor environmental quality and thermal comfort), building material, and building innovation due to selected parameters influence the bioclimatic dimension of the built environment. The residents of dwellings responded about their perception and satisfaction based on POE (Post-occupancy evaluation) (Khalil & Husin, 2009). Data were gathered by a standardized single-digit score on a five-point Likert scale (Likert, 1932), referred to as strong disagreement (1) to a strong agreement (5) to a defined requirement and condition. The analysis consists of an approach to quantitatively determine the balance between climatic conditions and the built environment, considering the necessity of the dwellers' health and safety and architectural and technological solutions (Amiri et al., 2020; Madhumathi & Sundarraja, 2014; Mohammadi et al., 2018; Nag, 2019). Furthermore, Table 2 depicts the methodology and a comprehensive criterion for scoring the parameters.

Table 2. Parameters for bioclimatic analysis and scoring methodology.

Parameters	Scoring criteria
Site and location	
Transportation (Local transportation - bicycle stand, green vehicle motor van stand) (Long-distance transportation - bus stand, railway station)	The score (1 to 5) depends on the distance from the house, where 1 (minimum) represents non-availability, that is, less human-friendly to residents, and 5 (maximum) indicates nearby, which is most human-friendly.
Surrounding area (Building surroundings - watershed, green area, outdoor space) (Area surroundings -construction activities, bazaar, schools/colleges)	The score (1 to 5) is based on availability and distance, where 1 (minimum) represents non-availability or absence, and 5 (maximum) indicates nearby and more influence on the resident's lifestyle.
Settlement (Housing settlement, cluster settlement)	The score (1 to 5) is based on the impact of settlement on the environment, 1 represents a more negative impact (less eco-friendly), and 5 indicates no or less impact (most eco-friendly).
Building design (Type of building, window, roof and inner design, kitchen, outer design)	The score (1 to 5) is based on the impact of the built facility on the environment, health, safety and comfort; 1 (minimum) indicates less eco-, human-, and energy-friendliness; 5 (maximum) represents most eco-, human-, and energy-friendliness.
Energy efficiency	
Indoor environmental conditions (Air movement, natural ventilation, and sunlight penetration) **Resident's behaviour and satisfaction** (Use of light and fan in the daytime, electricity expense, awareness about the misuse of electricity, and use of solar energy) **Use of cooking fuel or aids** (Cow dung cake, firewood, LPG, kerosene stove, etc.)	The energy efficiency includes (a) environmental conditions, (b) residents' behaviour and satisfaction, and (c) use of the cooking fuel or aids. The comprehensive score of the section (1 to 5) relates to residents' perception and satisfaction, where 1 (minimum) indicates strongly disagree or dissatisfied, whereas 5 (maximum) explains strongly agree or satisfied.

Table 2. *Cont.*

Parameters	Scoring criteria
Health and Safety	
Indoor environmental quality (Visual comfort, acoustic comfort, cleanliness, smell/odor, indoor thermal comfort, indoor air quality, indoor work productivity)	The section includes (a) indoor environmental quality, (b) heat-related illness, (c) SBS, and (d) thermal and humidity sensation and preference votes. A comprehensive score (1–5) is based on residents' perceptions and satisfaction, ranging from strongly disagreeing or dissatisfaction (score 1) to strong agreement with satisfaction (score 5).
Heat-related illness **Sick building syndrome (SBS)**	For heat-related illnesses and SBS syndrome, a score (1–5) is based on perception; a score (1) would indicate the absence of the problem (not at all). A score (5) relates to the presence of the problem (very much so).
Building material	
Floor, wall, and roof (Type and materials of floor and wall, roof, and partition materials) **Door, window, and ceiling** (Materials of door, window, glaze of window, and ceiling) **Recycling, reuse, and waste management**	The score (1 to 5) depends on the impact on the environment (eco-friendliness) and energy efficiency (energy-friendliness), where (1) corresponds to the minimum score that is less eco-friendly and energy-friendly. In contrast, a score (5) indicates the most eco-friendly and energy-friendly.
Building innovation	
(Garden, insulation, sanitation, and building envelope)	The score (1 to 5) refers to the occupants' perception; 1 indicates less eco-friendly, human-friendly, and energy-friendly; 5 relates to most eco-friendly, human-friendly, and energy-friendly.

2.3. Statistical Analysis

All statistical analyses were performed using the IBM® SPSS® software platform on both the original data and generated variables. The integrated upper 95% confidence limit value of five category parameters (site and location, energy efficiency, health and safety, and building innovation) was calculated to quantify the maximum and minimum total score for analyzing the building environmental performance of low-cost coastal dwellings in the bioclimatic aspect's dimensions. In addition, Cronbach's alpha reliability testing was performed to evaluate the internal consistency or reliability of the interactions among different bioclimatic components used in this study. Stated differently, the degree to which a measurement consistently captures an idea is its dependability, and one way to gauge this level of consistency is by the use of Cronbach's alpha (α).

3. Results

The perception and scoring of bioclimatic components by dwellers varied based on the area, type, and characteristics of the dwellings. The villagers' perception response of 97 different checkpoints and the dwelling characteristics parameters were presented in subsets of parameters based on different parameters of remote rural, rural, and semi-urban dwellings as stated above in Table 2. The statistical analysis of the subsets showed (Table 3) an upper confidence limit of 95%. For instance, local transportation has three parameters with the lowest and highest scores of 3 (1x3) and 15 (3x5). The upper 95% confidence limit is 12 out of 15, and 8 out of 10 as normalization against the unity score of 10. However, compared to long-distance transportation, which has two parameters with the lowest and highest scores of 2 and 10, the normalization score is 4 due to the unavailability and partial availability of rural and semi-urban areas. The highest and lowest scores of building surroundings are 3 (1x3) and 15 (5x3), having 10.8 of the upper 95% confidence limits (7 is the normalization value against a unity score of 10). In contrast, area surroundings have a score of 8 out of 10 as the upper value of 95% confidence limit. Types of settlement have two parameters with the lowest and highest scores of 2 (1x2) and 10 (5x2), and 7 is the upper value (normalization against a unity score of 10). The total of 12 parameters under the building design has an upper value of 95% confidence limit of 8, 8, 6, 5, and 7 out of 10. Furthermore, 16 parameters were considered under energy efficiency evaluation, and the upper values of 95% confidence limits are 7, 6, and 5. Similarly, 40 parameters under health and safety have values for 95% upper confidence limits of 8, 6, 5, 8, 5, and 5 accordingly. In addition, 13 parameters are included under building materials, and scores are 6, 8, and 7 out of 10 accordingly. Only 4 parameters are considered under building innovation and have a limit of upper 95% confidence limit of 6 (normalization against a unity score of 10) (Table 3). As the number of parameters differs in each subset, a normalization of the upper confidence limit was applied against a unity score of 10. Thus, the integrated total upper 95% confidence limit value of 285 of five categories was rounded to a normalized value of 150, with the relative influence of subsets of characteristics for different types of dwellings, categorized as remote rural, rural, and semi-urban.

Figure 3 depicts household communities' relative weightage (%) of different bioclimatic parameters. The availability of local transportation facilities is highest in rural communities compared to other communities due to the availability of bicycle stand, green vehicle, and motor van stand, whereas long-distance transportation facilities are available in semi-urban areas due to the presence of a railway station and bus stand. Various building design parameters in different household communities are highlighted in Figure 3 influenced by economic conditions, lifestyle, and community structure. The indoor environmental conditions of remote rural areas are higher than other communities due to natural ventilation, sunlight penetration, etc. Moreover, various comforts such as visual, acoustic, thermal, cleanliness, and human health-related disorders vary with different communities due to building structure, outdoor environment, etc. Building materials and innovations also vary with the household communities. This analysis indicates that the building's environmental performance in the bioclimatic dimension varied with the household communities. The composite scoring and the relative coverage of the enclosed graphical area helped compare the bioclimatic performance of houses of similar community environments.

Table 3. Normalized scoring of bioclimatic parameters for evaluation and comparison of rural coastal dwellings.

		Upper 95% Confidence limit	Normalization (against a unity score of 10)	The relative weightage (%)
Site and location				
Transportation	Local transportation (3 parameters - bicycle stand, green vehicle, motor van stand)	12	8	5.4
	Long-distance transportation (2 parameters - bus stand, railway station)	4.4	4	2.6
Surrounding area	Building surroundings (3 parameters - watershed, green area, outdoor space)	10.8	7	4.7
	Area surroundings (2 parameters – construction, bazaar, educational institute)	7.7	8	5.3
Settlement	Settlement (2 parameters - housing settlement, cluster settlement)	6.8	7	4.6
Building design	Type of building (2 parameters - form and layout of building)	8.4	8	5.4
	Window (3 parameters - location, opening, and design of window)	11.2	8	5.3
	Roof and inner design (3 parameters - roof, corridor, staircase)	8.6	6	4.0
	Kitchen (2 parameters - kitchen pattern and chimney use)	4.7	5	3.3
	Outer design (2 parameters – farmhouse/cattle shed, toilet)	7.2	7	4.0

Table 3. *Cont.*

		Upper 95% Confidence limit	Normalization (against a unity score of 10)	The relative weightage (%)
Energy efficiency				
Indoor environmental condition	Indoor environmental conditions (4 parameters - air movement, indoor ventilation, residents satisfied with air movement, sunlight penetration)	14.1	7	4.6
Residents' behavior and satisfaction	Residents' behavior and satisfaction (4 parameters - use of light and fan in the daytime, expense of electricity, use of solar energy, awareness about the misuse of electricity)	11.5	6	4.0
Cooking fuels	Cooking fuels (8 parameters - LPG, coal, cow dung cake, dry leaf, kerosene stove, firewood, gul (cooking fuel), others)	20.3	5	3.4
Health and Safety				
Indoor environmental quality	Visual comfort (3 parameters - natural day lighting, artificial lighting, and the overall quality of lighting)	12.3	8	5.4
	Acoustic comfort (2 parameters - noise or vibration and the overall quality of noise control)	6.4	6	4.0
	Cleanliness and smell (6 parameters - level of cleanliness, the smell from drainage or sewer, dumping ground, cow dung, chemicals, smoke in the room during cooking)	13.3	5	3.4
	Indoor quality (3 parameters - thermal comfort, air quality, work productivity)	12.4	8	5.4
Heat-related symptoms	Heat-related symptoms (18 parameters)	39.9	5	3.4
Sick building syndrome	Sick building syndrome (8 parameters)	16.9	5	3.3

Table 3. *Cont.*

		Upper 95% Confidence limit	Normalization (against a unity score of 10)	The relative weightage (%)
Building material				
Floor, wall, and roof	Floor, wall, and ceiling (6 parameters - type and materials of floor and wall, roof and partition materials)	17.7	6	4.0
Door, window, and ceiling	Door, window, and ceiling (4 parameters - materials of door, window, glaze of window, ceiling)	15.7	8	5.3
Recycling and reuse, waste management	Materials recycling and reuse, types and waste management facility (3 parameters)	9.7	7	4.5
Building innovation				
	Building innovation (4 parameters - garden, insulation, sanitation, building envelope)	12.6	6	4.0
Total		285	**150**	100

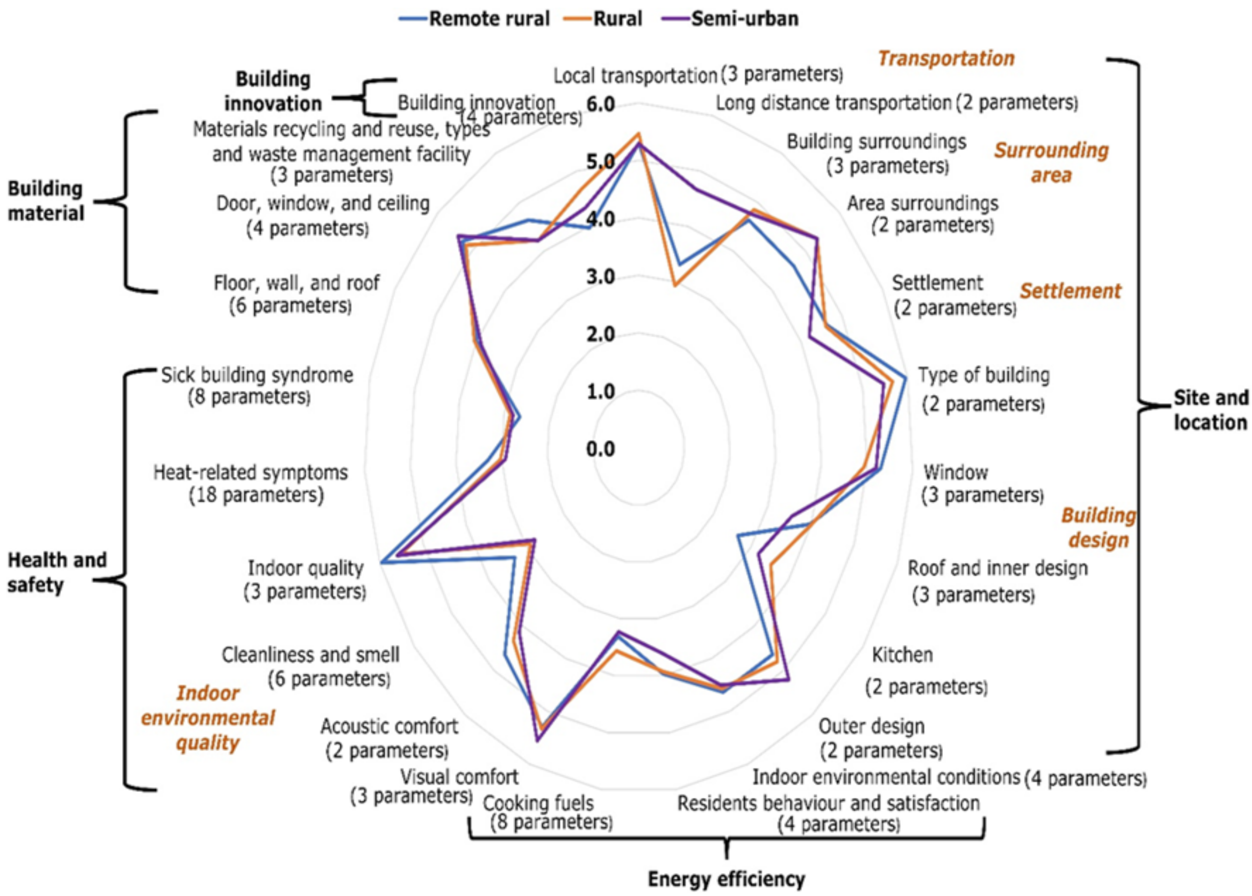

Figure 3. The relative weightage (%) of various bioclimatic parameters of remote rural, rural, and semi-urban dwellings.

4. Discussion

Previous studies reported guidelines for implementing green building concepts in large residential complexes, particularly in urban areas (De Masi et al., 2021; Doan et al., 2017; Faqih & Zayed, 2021; Nag, 2019). However, there is a knowledge gap in our existing understanding of the characterization of low-cost rural dwellings. This maiden endeavor explores bioclimatic elements of impoverished low-cost homes, with a representative analysis of coastal houses in Eastern India. The poor socioeconomic backgrounds of the households primarily determine the nature and structure of the settlements in the studied rural settings. Based on sample surveying, the perception response of the villagers and the performance characteristics of the dwellings were evaluated by normalization of weightage of different subsets of parameters of dwellings. A large matrix of parameters comprising 1332 households and 97 checkpoints was clustered into 23 subsets for different categories of homes. The analysis yielded some differences in internal consistency, as reflected in Cronbach's alpha reliability testing of 23 subsets. The reliability coefficients of room window features (location, opening, and design), cleanliness and smell, materials of the door, window and ceiling, sick building syndrome, settlement, building innovation, heat-related symptoms, transportation, acoustic and visual comfort, indoor environmental condition, ranged between $\alpha = 0.499$ and 0.859. The reliability level of Cronbach alpha (α) value was classified as 0.0–0.20 (less reliable), > 0.20–0.40 (rather reliable), > 0.40–0.60 (pretty reliable), > 0.60–0.80 (reliable), and > 0.80–1.00 as 'very reliable' (Wahyudi, 2016). Hence, our analysis indicates a pretty reliable ($\alpha = 0.49$ to 0.6), reliable ($\alpha = 0.6$ to 0.8), and very reliable ($\alpha > 0.80$) outcomes of the interaction between different components as stated above. Despite a consistent 'reliable' to 'very reliable' α obtained for most of the parameters and their interactions, very few 'pretty reliable' α values for some of the parameters might have resulted from the heterogeneous construct of the checkpoint or exogenous factors, such as site or location and/or seasonal variations. Overall, this study successfully quantifies the bioclimatic performance of low-cost coastal rural dwellings. This may help develop building regulations or guidelines for the passive design of dwellings in rural coastal regions of India.

The primary aim of the bioclimatic design strategy is to mitigate the impact of climate change on occupants of indoor environments (Bera & Nag, 2022). The passive design strategies of the buildings are based on the local climate, and surrounding environment to improve the quality of the indoor built environment, energy efficiency, and thermal comfort (Bera & Nag, 2022). This study highlighted the different criteria of individual parameters for the assessment of building environmental performance in the bioclimatic dimension and developed the composite scoring to evaluate the bioclimatic parameters of the built environment of the different climatic regions. As stated, the prevailing environmental performance ratings systems have their application domain primarily to the well-structured built environment of geographical priority. The present contribution brought out a comprehensive evaluation of bioclimatic aspects of low-cost dwellings and accordingly suggested an approach to scoring components (design strategies, indoor environmental quality, thermal comfort, and energy efficiency). The premise of the evaluation is to ascertain (a) the impact of the dwellings on the environment and related components (eco-friendly), (b) human health, safety, and comfort (human-friendly), and (c) the energy efficiency of the dwelling structure (energy-friendly). Large-scale validation of the suggested evaluation process and scoring of bioclimatic dimensions may further evolve a new quantitative approach to rating the performance of a rural built environment.

In addition, ensuring the safety of low-cost coastal dwellings is of utmost importance, especially in areas prone to natural disasters such as floods, cyclones, storm surges, tornados, and tsunamis (Zisan et al., 2013). To mitigate the risks associated with coastal living, certain safety measures can be incorporated into low-cost coastal dwellings. These measures include: (a) using durable and weather-resistant materials that can withstand the corrosive effects of saltwater and the impact of high winds, (b) designing the dwelling with proper ventilation to reduce the risk of mold growth in humid coastal environments, (c) opting for simple and streamlined architectural designs to minimize wind resistance and reduce the risk of structural damage during storms, (d) implementing effective drainage systems to manage heavy rainfall and prevent water accumulation around the dwelling, (e) establishing community-based early warning systems to alert residents about approaching storms, allowing them to evacuate promptly, and (f) ensuring adequate airflow to help dry out the building after flooding.

Coastal areas are vulnerable to climate change and need affordable and durable housing solutions. Research in this area is crucial to finding innovative and sustainable solutions for low-cost coastal dwellings. This research should address the unique challenges posed by coastal environments and contribute to overall resilience in the face of climate change. Some recommendations for future research are given below:

- Develop building materials that are low-cost, climate-responsive, and capable of withstanding saltwater exposure, high winds, and storm surges.
- Explore innovative materials that offer both durability and environmental benefits such as bamboo, recycled plastics, or sustainable composites.
- Implement passive design strategies that optimize natural ventilation, day lighting, and thermal performance to reduce the reliance on energy-intensive climate control systems.
- Integrate renewable energy systems, such as solar panels, wind turbines, or tidal energy, to power low-cost coastal dwellings. Research ways to make these systems more affordable, accessible, and adaptable to diverse coastal environments.
- Use ecological infrastructure, such as mangrove restoration, dune stabilization, and wetland preservation, as natural buffers against coastal erosion and storm impacts.
- Explore landscaping and green roofing options that enhance the aesthetics of low-cost coastal dwellings.
- Promote community engagement in the design and construction processes to ensure that local knowledge and needs are considered.
- Integrate traditional building techniques and indigenous knowledge into modern, low-cost coastal dwelling solutions.
- Advocate for policy frameworks that incentivize the adoption of sustainable and resilient building practices for low-cost coastal dwellings.
- Modify or enhance existing policies to promote eco-friendly coastal housing initiatives.

5. Conclusions

This study provides a scoring criteria-based quantitative approach to evaluate bioclimatic components of coastal rural dwellings, including remote rural, rural, and semi-urban low-cost houses of coastal regions of the Sundarbans, eastern India (West Bengal). The bioclimatic aspects are associated with building environmental performance, such as energy efficiency, thermal comfort, and indoor environmental quality. The proposed scoring process and evaluation criteria may demand emendation with regions (like urban environment) and building types (commercial, office, industries). Overall, this study significantly addressed the bioclimatic performance i.e., eco-human-energy friendliness of low-cost coastal rural dwellings, which may be useful to develop strategies or building codes for the passive design of rural dwellings in the coastal areas of India. This method and analysis in this study may extend the evaluation of dwellings' environmental performance in other coastal regions based on the selected criteria.

Supplementary Materials: The following supporting information can be downloaded at: https://sccpress-my.sharepoint.com/:b:/p/travismalone/EWQCWdvaTFdBn5_uuFwG6yYBSzaP1NSUsvm-PE2f4Uid5Q?e=Rox5sr&download=1, Table S1: Design of the questionnaire datasheet for the perception survey of the dwellers.

CRediT Author Statement: Mahadev Bera: Conceptualization, Methodology, Software, Validation, Resources, Formal analysis, Investigation, Data curation and Writing – Original draft; **Pranab Kumar Nag:** Conceptualization, Methodology, Resources, Supervision, Project administration, Funding acquisition and Writing – Review & Editing; **Sumanta Das:** Conceptualization, Methodology, Validation, Supervision and Writing – Review & Editing.

Data Availability Statement: The data presented in this study are available within the article or supplementary material [Table S1: Design of the questionnaire datasheet for the perception survey of the dwellers].

Funding: This research was partially funded by the Government of West Bengal (India) under the Swami Vivekananda Merit cum Means Scholarship.

Conflicts of Interest: The authors declare no conflict of interest.

Acknowledgments: The authors gratefully acknowledge the partial financial support under the Swami Vivekananda Merit cum Means Scholarship by the Government of West Bengal, India. In addition, the authors convey sincere thanks to the University and its associated staff for their support in conducting the study.

References

Aghimien, E. I., Li, D. H. W., & Tsang, E. K. W. (2022). Bioclimatic architecture and its energy-saving potentials: A review and future directions. *Engineering, Construction and Architectural Management*, *29*(2), 961–988. https://doi.org/10.1108/ECAM-11-2020-0928

Amiri, M., Tarkesh, M., Jafari, R., & Jetschke, G. (2020). Bioclimatic variables from precipitation and temperature records vs. remote sensing-based bioclimatic variables: Which side can perform better in species distribution modeling? *Ecological Informatics*, *57*, 101060. https://doi.org/10.1016/j.ecoinf.2020.101060

Assefa, S., Lee, H. Y., & Shiue, F. J. (2022). Sustainability performance of Green Building Rating Systems (GBRSs) in an Integration Model. *Buildings*, *12*(2), 208. https://doi.org/10.3390/buildings12020208

Attia, S., Lacombe, T., Rakotondramiarana, H. T., Garde, F., & Roshan, G. (2019). Analysis tool for bioclimatic design strategies in hot humid climates. *Sustainable cities and society*, *45*, 8–24. https://doi.org/10.1016/j.scs.2018.11.025

Austin, M. C., Castillo, M., Da Silva, Á. D. M., & Mora, D. (2020). Numerical assessment of bioclimatic architecture strategies for buildings design in tropical climates: A case of study in Panama. In *E3S web of conferences*, *17*, 02006. https://doi.org/10.1051/e3sconf/202019702006

Bal, S., & Matzarakis, A. (2022). Temporal analysis of thermal bioclimate conditions between Kolkata (India) and its three neighbouring suburban sites. *Theoretical and Applied Climatology*, 1–18. https://doi.org/10.1007/s00704-022-04010-x

Balasbaneh, A. T., & Bin Marsono, A. K. (2017). Proposing of new building scheme and composite towards global warming mitigation for Malaysia. *International Journal of Sustainable Engineering*, *10*(3), 176–184. https://doi.org/10.1080/19397038.2017.1293184

Balasbaneh, A. T., & Bin Marsono, A. K. (2018). New residential construction building and composite post and beam structure toward global warming mitigation. *Environmental Progress & Sustainable Energy*, *37*(4), 1394–1402. https://doi.org/10.1002/ep.12807

Barea, G., Mercado, M. V., Filippin, C., Monteoliva, J. M., & Villalba, A. (2022). New paradigms in bioclimatic design toward climatic change in arid environments. *Energy and Buildings*, *266*, 112100. https://doi.org/10.1016/j.enbuild.2022.112100

Bazzato, E., Rosati, L., Canu, S., Fiori, M., Farris, E., & Marignani, M. (2021). High spatial resolution bioclimatic variables to support ecological modelling in a Mediterranean biodiversity hotspot. *Ecological Modelling*, *441*, 109354. https://doi.org/10.1016/j.ecolmodel.2020.109354

Bera, M., & Nag, P.K. (2021). Bioclimate in Built Environment. *Ergonomics International Journal*, *5*(5), 000277. https://doi.org/10.23880/eoij-16000277

Bera, M., & Nag, P.K. (2022). Bioclimatic Design of Low-cost Rural Dwellings. *Frontiers in Built Environment*, *8*, 773108. https://doi.org/10.3389/fbuil.2022.773108

Bhamare, D. K., Rathod, M. K., & Banerjee, J. (2020). Evaluation of cooling potential of passive strategies using bioclimatic approach for different Indian climatic zones. *Journal of Building Engineering*, *31*, 101356. https://doi.org/10.1016/j.jobe.2020.101356

Braulio-Gonzalo, M., Jorge-Ortiz, A., & Bovea, M. D. (2022). How are indicators in Green Building Rating Systems addressing sustainability dimensions and life cycle frameworks in residential buildings? *Environmental Impact Assessment Review*, *95*, 106793. https://doi.org/10.1016/j.eiar.2022.106793

Chandel, S. S., Sharma, V., & Marwah, B. M. (2016). Review of energy efficient features in vernacular architecture for improving indoor thermal comfort conditions. *Renewable and Sustainable Energy Reviews*, *65*, 459–477. https://doi.org/10.1016/j.rser.2016.07.038

De Masi, P. D. R. F., Mastellone, P. D. C. M., & Vanoli, F. P. G. P. (2021). Building rating systems: A novel review about capabilities, current limits and open issues. *Sustainable Cities and Society*, 103498. https://doi.org/10.1016/j.scs.2021.103498

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. *Building and Environment*, *123*, 243–260. https://doi.org/10.1016/j.buildenv.2017.07.007

Elaouzy, Y., & El Fadar, A. (2022). A multi-level evaluation of bioclimatic design in Mediterranean climates. *Sustainable Energy Technologies and Assessments*, *52*, 102124. https://doi.org/10.1016/j.seta.2022.102124

Elaouzy, Y., & El Fadar, A. (2023). Sustainability of building-integrated bioclimatic design strategies depending on energy affordability. *Renewable and Sustainable Energy Reviews*, *179*, 113295. https://doi.org/10.1016/j.rser.2023.113295

Faqih, F., & Zayed, T. (2021). A comparative review of building component rating systems. *Journal of Building Engineering*, *33*, 101588. https://doi.org/10.1016/j.jobe.2020.101588

Forero, B., Hechavarría, J., Vega, R. (2020). Bioclimatic design approach for low-income dwelling at Monte Sinahí, Guayaquil. In Di Bucchianico, G. (ed.), *Advances in design for inclusion. AHFE 2019. Advances in intelligent systems and computing: (pp. 176–185).* Springer. https://doi.org/10.1007/978-3-030-20444-0_17

Gupta, S. K., Chanda, P. R., & Biswas, A. (2023). A 2E, energy and environment performance of an optimized vernacular house for passive cooling-Case of North-East India. *Building and Environment*, *229*, 109909. https://doi.org/10.1016/j.buildenv.2022.109909

Henderson, F., Steiner, A., Farmer, J., & Whittam, G. (2020). Challenges of community engagement in a rural area: The impact of flood protection and policy. *Journal of Rural Studies*, *73*, 225–233. https://doi.org/10.1016/j.jrurstud.2019.11.004

Hosseini, A. (2022). Evaluation of bioclimatic design strategies in Esfahak village using Mahoney method. *Journal of Cultural Heritage Management and Sustainable Development*. https://doi.org/10.1108/JCHMSD-12-2021-0210

Hwang, R. L., & Chen, W. A. (2022). Identifying relative importance of solar design determinants on office building façade for cooling loads and thermal comfort in hot-humid climates. *Building and Environment*, *226*, 109684. https://doi.org/10.1016/j.buildenv.2022.109684

Khalil, N., & Husin, H. N. (2009). Post occupancy evaluation towards indoor environment improvement in Malaysia's office buildings. *Journal of sustainable development*, *2*(1), 186–191. https://doi.org/10.5539/jsd.v2n1p186

Li, Y. L., Han, M. Y., Liu, S. Y., & Chen, G. Q. (2019). Energy consumption and green-house gas emissions by buildings: A multi-scale perspective. *Building and Environment*, *151*, 240–250. https://doi.org/10.1016/j.buildenv.2018.11.003

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of psychology*.

Liu, S., Kwok, Y. T., Lau, K. K. L., Ouyang, W., & Ng, E. (2020). Effectiveness of passive design strategies in responding to future climate change for residential buildings in hot and humid Hong Kong. *Energy and Buildings*, *228*, 110469. https://doi.org/10.1016/j.enbuild.2020.110469

Loftness, V. (2020). Sustainable built environments: Introduction. *Sustainable Built Environments*, 1–16. https://doi.org/10.1007/978-1-0716-0684-1_925

Madhumathi, A., & Sundarraja, M.C. (2014). Understanding climate for sustainable building design – A case study in warm humid region in India. *Journal of Applied Sciences Research*, *10*(2), 69–87.

Menna, C., Felicioni, L., Negro, P., Lupíšek, A., Romano, E., Prota, A., & Hájek, P. (2022). Review of methods for the combined assessment of seismic resilience and energy efficiency towards sustainable retrofitting of existing European buildings. *Sustainable Cities and Society*, *77*, 103556. https://doi.org/10.1016/j.scs.2021.103556

Misra, D. (2023). Green energy in West Bengal, India: Status, scope, and future challenges. In Gupta, O.H., Singh, S.N., Malik, O.P. (Eds.), *Recent advances in Power Systems. Lecture Notes in Electrical Engineering* (pp. 46–62). Springer. https://doi.org/10.1007/978-981-19-6605-7_4

Mohammadi, A., Saghafi, M. R., Tahbaz, M., & Nasrollahi, F. (2018). The study of climate-responsive solutions in traditional dwellings of Bushehr City in Southern Iran. *Journal of Building Engineering*, *16*, 169–183. https://doi.org/10.1016/j.jobe.2017.12.014

Nag, P. K. (2019). Bioclimatic approach: Thermal environment. In P. K. Nag (Ed.), *Office Buildings: Health, Safety and Environment* (pp. 243–278). Springer Singapore. https://doi.org/10.1007/978-981-13-2577-9_9

Pontes, R. H., Najjar, M. K., Hammad, A. W., Vazquez, E., & Haddad, A. (2022). Adapting the Olgyay bioclimatic chart to assess local thermal comfort levels in urban regions. *Clean Technologies and Environmental Policy*, *24*(2), 661–675. https://doi.org/10.1007/s10098-021-02158-0

Putra, I. D. G. A., Nimiya, H., Sopaheluwakan, A., Kubota, T., Lee, H. S., Pradana, R. P., Alfata, M. N. F., Perdana, R. B., Permana, D. S., & Riama, N. F. (2022). Development of climate zones for passive cooling techniques in the hot and humid climate of Indonesia. *Building and Environment*, *226*, 109698. https://doi.org/10.1016/j.buildenv.2022.109698

Semahi, S., Zemmouri, N., Singh, M. K., & Attia, S. (2019). Comparative bioclimatic approach for comfort and passive heating and cooling strategies in Algeria. *Building and Environment*, *161*, 106271. https://doi.org/10.1016/j.buildenv.2019.106271

Subhashini, S., & Thirumaran, K. (2018). A passive design solution to enhance thermal comfort in an educational building in the warm humid climatic zone of Madurai. *Journal of Building Engineering*, *18*, 395–407. https://doi.org/10.1016/j.jobe.2018.04.014

Tamaskani Esfehankalateh, A., Farrokhzad, M., Tamaskani Esfehankalateh, F., & Soflaei, F. (2022). Bioclimatic passive design strategies of traditional houses in cold climate regions. *Environment, Development and Sustainability*, 1–42. https://doi.org/10.1007/s10668-021-01855-6

Tiwari, A. K. (2023). A review on renewable energy sources, potential and policy in India. *Sustainable Computing: Transforming Industry 4.0 to Society 5.0*, 1–30. https://doi.org/10.1007/978-3-031-13577-4_1

Wahyudi, K. (2016). The effect of service recovery justice perceived satisfaction and impact on relationship quality, and purchase intention at Pt Indotruck Utama as One of Volvo Trucks Indonesia's Dealer. *Business and Entrepreneurial Review*, *16*(1), 63–102. https://doi.org/10.25105/ber.v16i1.4910

Watson, D. (2020). Bioclimatic design. *Sustainable Built Environments*, 19–41. https://doi.org/10.1007/978-1-0716-0684-1_225

World Meteorological Organization. (2021). State of the global climate 2021. https://public.wmo.int/en/media/press-release/state-of-climate-2021-extreme-events-and-major-impacts#:~:text=The%20global%20mean%20temperature%20for,warmest%20year%20on%20record%20globally

Xhexhi, K. (2023). Bioclimatic eco-renovation concept design and strategies. The use of different materials. In K. Xhexhi (Ed.), *Ecovillages and Ecocities: Bioclimatic Applications from Tirana, Albania* (pp. 191–224). Springer International Publishing. https://doi.org/10.1007/978-3-031-20959-8_8

Zahiri, S., & Altan, H. (2020). Improving energy efficiency of school buildings during winter season using passive design strategies. *Sustainable Buildings*, *5*, 1. https://doi.org/10.1051/sbuild/2019005

Zhen, M., Sun, C., & Goh, B. H. (2016). Simulating passive design strategies of rural residential buildings in severe cold regions of northeast China. In G. Hua (Ed.), *Smart Cities as a Solution for Reducing Urban Waste and Pollution* (pp. 39–65). IGI Global. https://doi.org/10.4018/978-1-5225-0302-6.ch002

Zisan, M. B., Alam, M. R., Hasan, M. M., & Akter, S. S. (2013). Cyclone resistant low-cost housing in coastal area of Bangladesh. *Int. J. Sci. Environ. Technol*, *2*, 48–55.

Zr, D. L., & Mochtar, S. (2013). Application of bioclimatic parameter as sustainability approach on multi-story building design in tropical area. *Procedia Environmental Sciences*, *17*, 822–830. https://doi.org/10.1016/j.proenv.2013.02.100