

An integrated framework for a sustainable hotel complex in Ghazni: A climate-responsive, culturally-attuned model for arid climates

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Abstract: This study addresses the critical need for sustainable hospitality infrastructure in regions with distinct climatic and cultural contexts, focusing on Ghazni, Afghanistan (AFG). It answers two primary research questions: (1) What quantified energy and carbon reductions can be achieved by integrating vernacular passive strategies with active renewable systems in a hotel model for Ghazni? (2) What design parameters ensure cultural relevance, technical feasibility, and local adaptability? The study develops and evaluates an integrated, context-specific Sustainable Hotel Model (SHM) through a mixed-methods approach, combining socio-technical surveys (N = 250), expert interviews (N = 24), and building performance simulation using Autodesk Revit (BIM) and EnergyPlus. A household survey revealed strong public endorsement for sustainability (76% priority) and solar energy (94.95% support), alongside significant gaps in current hotel practices (77.78% perceived no energy efficiency (EE) measures). Expert interviews informed a four-pillar design framework comprising 65 principles across the Socio-Cultural, Economic, Environmental, and Technical domains. Simulation results demonstrate that the proposed SHM achieves a 14.68% reduction in total site energy consumption, a 20.66% reduction in cooling demand, and meets 91.6% of its annual electricity demand via on-site solar photovoltaic (PV) systems. Lifecycle carbon assessment shows a 73.3% reduction in total carbon emissions, driven primarily by an 80.3% reduction in embodied carbon through local, low-embodied-energy materials. The study concludes that authentic sustainability in such contexts requires a synergistic system where high environmental performance is achieved through, not at the expense of, cultural preservation and economic vitality. This research provides a simulation-evaluated, replicable blueprint for decarbonizing the hospitality sector and promoting sustainable regional development in arid, culturally significant regions.

Keywords: sustainable hotel design; building performance simulation; lifecycle carbon assessment; renewable energy integration; context-sensitive design; Ghazni

1. Introduction

The global hospitality sector is recognized as one of the most resource-intensive segments of the built environment, characterized by continuous operation, high service demands, and substantial energy and water consumption [1]. Studies indicate that approximately 75% of a hotel's environmental impact stems from the excessive use of energy, water, and non-sustainable materials, leading to significant air, water, and soil pollution [1,2]. Consequently, hotels are critical targets for clean energy integration and

carbon mitigation strategies, especially as the building sector accounts for a significant share of global final energy use and carbon emissions [2–4].

Sustainable development principles have been increasingly integrated into tourism, with international organizations emphasizing that environmental stewardship in hotels must extend beyond waste management to include EE, renewable energy adoption, water conservation, and responsible material selection [5–7]. The United Nations World Tourism Organization reports that effective energy management in hotels can reduce carbon dioxide emissions by up to 30% while lowering operational costs [8]. Furthermore, sustainable hotel practices enhance brand image, customer satisfaction, and long-term economic performance [9–11]. The sector’s 24/7 operational nature imposes complex challenges on energy management systems, making EE, waste management, and water conservation critical components of sustainable operations [12]. Implementing integrated sustainability strategies allows operators to reduce costs while improving environmental performance and competitiveness [12,13], a trend accelerated by growing consumer demand for environmentally responsible accommodations [14].

Climate change intensifies the urgency for sustainable design. Rising global temperatures and the increasing frequency of extreme weather events directly threaten tourism infrastructure and destinations [15,16]. Without effective mitigation, global temperature increases exceeding 3 °C by the end of the century remain plausible, posing severe risks to the tourism sector and related economic systems [16]. Therefore, clean-energy-oriented hotel design has emerged as a strategic response to both climate risks and sustainability imperatives [17,18].

Beyond technological solutions, culturally and climatically responsive architecture is vital for reducing energy demand. Vernacular architecture, shaped by local climate, materials, and socio-cultural practices, offers proven passive design strategies that enhance thermal comfort while minimizing reliance on mechanical systems [19,20]. Principles such as compact massing, courtyards, shading, and natural ventilation can significantly reduce energy consumption in harsh climates [19–21]. Adapting these strategies to contemporary design improves thermal performance and environmental compatibility [22, 23]. These considerations are particularly relevant in AFG, where the building sector faces energy insecurity, inefficient construction practices, and limited renewable energy deployment despite substantial solar potential [24, 25]. For instance, integrating vernacular architecture into sustainable urban housing has been shown to enhance resilience, cultural continuity, and environmental performance in Afghan settlements [26].

Ghazni, AFG, characterized by a cold semi-arid climate with pronounced seasonal variations, presents significant opportunities for climate-responsive and solar-oriented architectural solutions [27]. Building orientation, envelope performance, and solar access can lead to substantial variations in annual energy demand in comparable climatic conditions [27,28]. To quantify the effectiveness of such strategies, building performance simulation has become an essential research and design tool. EnergyPlus is recognized as a robust simulation engine for modeling complex building energy behavior and supporting evidence-based sustainable design decisions [29,30]. Simulation-based studies confirm that combining passive design with renewable energy

systems can achieve significant reductions in energy consumption and operational emissions in hotel and non-residential buildings [31–33]. This approach aligns with findings on EE in smart schools using renewable energy strategies, demonstrating the replicable benefits of integrated renewable systems in public buildings under similar climatic constraints [34].

Within the Afghan context, performance-driven sustainability research remains limited. However, available studies demonstrate that integrating renewable energy systems with climate-responsive design substantially improves EE and indoor environmental quality in institutional buildings [35,36]. Building upon this foundation and the broader international literature, this study addresses a critical gap by proposing and rigorously evaluating a climate-responsive and culturally integrated hotel model for Ghazni, AFG. The model synthesizes vernacular passive strategies with active clean energy systems, including solar PVs and water recycling, in line with international sustainability frameworks such as LEED and BREEAM [37,38].

The tourism sector in AFG, particularly in historic cities like Ghazni, remains underdeveloped despite significant cultural heritage and tourism potential [39]. A primary impediment is the absence of modern, eco-friendly accommodations that meet international performance standards. Existing facilities often rely on inefficient construction practices, conventional fuels, and designs poorly adapted to local climate and culture, resulting in excessive energy and water consumption, higher carbon emissions, and inadequate thermal comfort [24, 39, 40]. Consequently, the region struggles to fully leverage tourism for economic growth and sustainable development.

Sustainable hotel design and vernacular architecture are widely recognized for enhancing EE, thermal comfort, and cultural relevance in buildings [17, 21, 41]. However, in AFG, particularly in historic cities such as Ghazni, there is a critical lack of applied, quantitative research integrating these principles within the local climatic, socio-economic, and cultural context. Existing hotels often rely on inefficient construction practices, conventional fuels, and designs disconnected from the local climate and culture, resulting in excessive energy and water consumption, high carbon emissions, and inadequate thermal comfort. Consequently, the region's tourism sector remains underdeveloped, limiting opportunities for sustainable economic growth.

Despite the global literature on sustainable and vernacular design, few studies provide simulation-validated models that combine passive vernacular strategies with active renewable energy systems for hotels in cold semi-arid climates like Ghazni [31, 42]. Moreover, translating theoretical sustainability frameworks into practical, replicable building designs tailored to Afghan conditions remains largely unexplored. This creates a key knowledge gap: how can vernacular architectural principles be effectively synthesized with modern clean energy systems to create a holistic SHM that is technically feasible, culturally appropriate, and economically viable in Ghazni, AFG? Additional questions include: (1) What is the quantified performance (energy conservation and operational carbon reduction) of such an integrated model compared to a conventional hotel baseline, as validated through building performance simulation? (2) What are the key design parameters and implementation strategies that ensure the model's cultural relevance, technical

feasibility, and local adaptability? To address this gap, this research develops and quantitatively evaluates an integrated hotel prototype that combines passive vernacular strategies, such as natural ventilation, use of local materials, and optimized building orientation, with active renewable energy and water management systems, including solar PV and greywater recycling. Building performance simulation (Autodesk Revit and EnergyPlus) is employed to rigorously quantify energy use, operational carbon emissions, and thermal comfort relative to a conventional baseline. The study also identifies design strategies to ensure practicality, affordability, and cultural appropriateness, facilitating potential replication across similar contexts.

The primary aim of this study is to develop a replicable, climate-responsive, and culturally integrated hotel model to advance energy conservation and reduce operational carbon in Ghazni. The specific objectives are:

- (1) Analyze the climatic, cultural, and environmental conditions of Ghazni to inform context-specific design parameters.
- (2) Develop a hotel prototype that integrates passive vernacular strategies with active renewable energy and water management systems.
- (3) Employ building performance simulation to quantify the model's energy use, carbon emissions, and compare it to a conventional hotel.
- (4) Formulate actionable recommendations for implementation, considering technical, economic, and cultural factors to ensure practical adoption.

The novelty and significance of this research are multi-fold. Firstly, it provides empirical evidence through simulation data demonstrating significant energy (14.68%) and carbon (73.3%) reductions. Secondly, it establishes a methodological framework for integrating vernacular design and modern renewable technologies in hotel buildings. Thirdly, it delivers a practical, simulation-validated prototype to guide architects, developers, and policymakers. Lastly, it contributes to the academic literature on clean energy buildings by filling a contextual gap and demonstrating the potential synergy of vernacular wisdom and contemporary sustainability science [43–45].

While tailored to Ghazni, the methodological framework, combining climatic analysis, vernacular adaptation, renewable energy integration, and performance simulation, is generalizable to other cold semi-arid regions in Central and South Asia. The design emphasizes locally available materials, skills, and maintainable systems, reducing costs and supporting local economies. Partnerships with authorities, NGOs, and the private sector are highlighted as essential for practical deployment and long-term operational success.

While the proposed framework provides a simulation-validated approach for hotel buildings in cold semi-arid climates, several limitations warrant acknowledgment. Firstly, EnergyPlus simulations assume idealized occupancy schedules that may deviate from real-world patterns. Secondly, embodied carbon estimates rely on material databases that may not fully represent local supply chain conditions in Afghanistan. Lastly, the analysis focuses on operational energy reductions, with a full lifecycle assessment incorporating end-of-life considerations remaining beyond the current scope.

Compared to alternative approaches such as net-zero energy frameworks, which

emphasize strict envelope performance but often lack integration with vernacular strategies, the proposed framework offers a performance-based, context-adaptive methodology. Unlike prescriptive green building rating systems (e.g., LEED, BREEAM) that require external certification, this approach is implementable without third-party verification, enhancing accessibility in resource-constrained settings.

Regarding generalizability, while this study targets hotel typologies, the core framework, comprising climatic analysis, passive vernacular adaptation, active renewable system integration, and performance simulation, is transferable to other building types. Residential complexes, educational facilities, and small-scale commercial buildings in analogous cold semi-arid regions (e.g., parts of Iran, Tajikistan, and northern Pakistan) would benefit from similar methodological steps. Future research should validate the framework's applicability across these typologies and climatic zones.

In conclusion, this research addresses a critical knowledge gap by providing a context-sensitive, validated solution for sustainable hotel design in AFG. It demonstrates how climate-responsive architecture, vernacular principles, and renewable energy integration can collectively enhance EE, reduce carbon emissions, and respect local cultural identity. The study advances both practical development and the scholarly field of clean energy buildings, offering a blueprint for sustainable tourism infrastructure in under-researched, high-potential regions.

Geographical location and climatic context of the study area

This study was conducted in Ghazni Province, located in the south-eastern AFG at approximately 33.55° N latitude and 68.42° E longitude [41]. AFG is a landlocked and predominantly mountainous country characterized by a continental climate with pronounced seasonal and diurnal temperature variations. Extreme climatic conditions are common, with winter temperatures in high-altitude regions falling below $-20\text{ }^{\circ}\text{C}$ and summer temperatures in southern lowlands frequently exceeding $35\text{ }^{\circ}\text{C}$ [41,42].

Ghazni Province represents a cold semi-arid climatic zone, marked by long, cold winters and relatively warm summers. The annual temperature range typically varies from approximately $-10\text{ }^{\circ}\text{C}$ in winter to $35\text{ }^{\circ}\text{C}$ in summer, accompanied by low annual precipitation and limited humidity [42, 46]. These climatic characteristics impose significant thermal stress on buildings, particularly during the heating season, and highlight the necessity for climate-responsive and energy-efficient building design strategies (**Figure 1**).

The built environment in Ghazni is dominated by one- to three-story residential and mixed-use buildings, concentrated mainly in Ghazni City. Construction practices typically rely on non-insulated concrete, mud masonry, and fired brick, often combined with poor thermal envelopes and single-glazed fenestration systems [47]. These construction characteristics result in substantial heat losses during winter and overheating risks in summer, leading to high energy demand for space conditioning.

This challenge is further compounded by the limited reliability of the central electricity grid, which forces households and commercial buildings, including hotels, to depend heavily on traditional fuels and decentralized energy sources [48]. The convergence of harsh climatic conditions, energy-inefficient building stock, and

socio-economic constraints makes Ghazni Province a critical case study for developing localized, climate-responsive, and clean-energy-integrated hotel design and retrofit models.

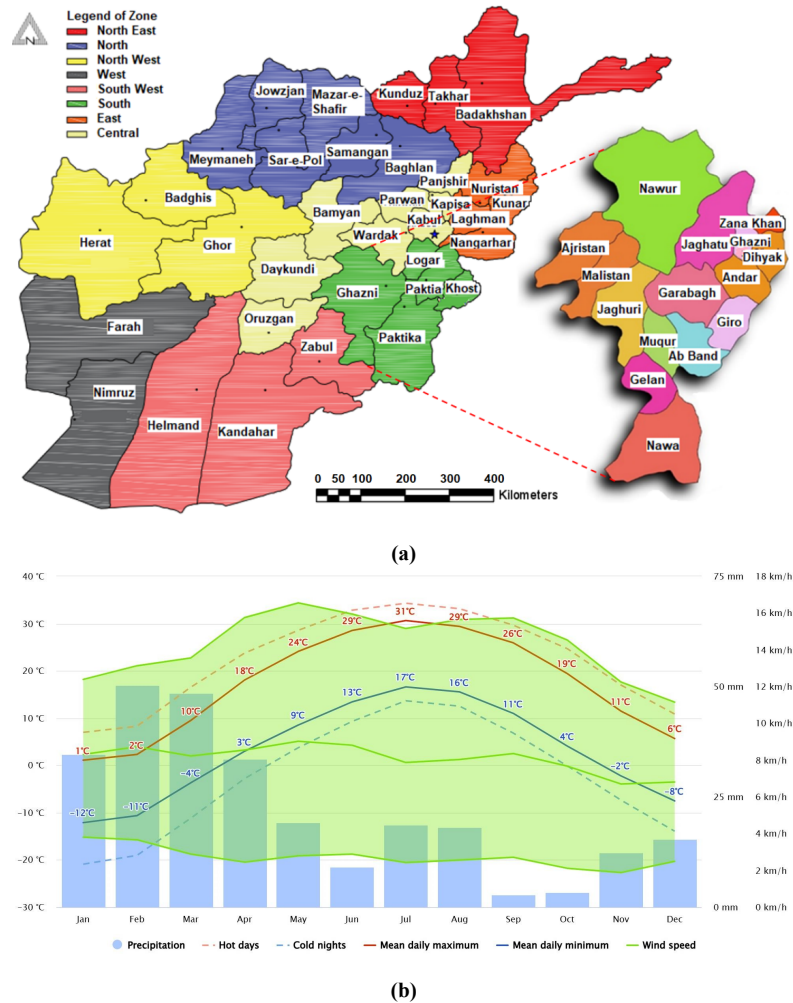


Figure 1. Study location and climatic characteristics of the case study area. (a) Geographic location of Ghazni Province, AFG; (b) Key climatic parameters for Ghazni, including precipitation, air temperature, and windspeed.

Source: **Figure 1a** from Authors, **Figure 1b** from Meteoblue [46].

2. Materials and methods

This study employs a novel, integrated mixed-methods methodology that synergizes field-based qualitative research with advanced computational modeling to develop a climate-responsive, culturally integrated, and environmentally SHM for Ghazni, AFG. While mixed-methods designs are common, the novelty of this research lies in its structured, five-phase sequential and iterative framework, which systematically synthesizes global sustainability standards with localized data. This process ensures the proposed model is not only technically viable according to international benchmarks but also deeply responsive to Ghazni’s specific climatic conditions, cultural heritage, and Islamic values.

The methodology is designed to translate context-specific socio-cultural, climatic, and economic constraints into quantifiable building performance parameters. Data from field surveys, expert interviews, and site documentation directly inform the

creation of a digital prototype in Autodesk Revit, which undergoes rigorous parametric energy analysis. Crucially, the optimization of key design variables, such as Window-to-Wall Ratio (WWR), thermal mass, and solar shading, is explicitly guided by locally gathered qualitative data on material availability, cultural preferences, and economic feasibility. This closed-loop approach ensures the final architectural model is not only optimized for energy performance but is also practically viable, culturally resonant, and technically replicable within the specific context of Ghazni. The research was executed in five sequential, interdependent phases, as detailed below and illustrated in **Figure 2**.

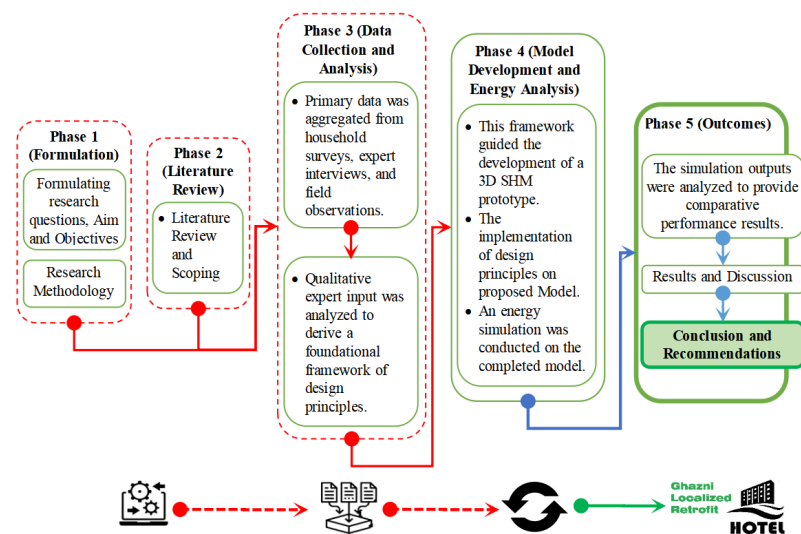


Figure 2. General methodological approach of the study.

In **Figure 2**, the upper panel presents the five sequential research phases (Formulation, Literature Review, Data Collection and Analysis, Model Development and Energy Analysis, and Outcomes). The lower panel illustrates the key activities and outputs within each phase, with icons representing the primary methods or tools employed (e.g., surveys, interviews, BIM simulation). Arrows indicate the iterative feedback loops between phases, particularly between expert input and model refinement.

2.1. Phase 1: Defining research aims, questions, and scope

This foundational phase established the research's direction by defining its core objectives, central problem, and key research questions. The scope was carefully delineated to focus on designing an SHM that integrates global sustainability principles with the specific climatic, cultural, and socio-economic conditions of Ghazni. The geographical boundaries of the study, its scientific necessity, and expected outcomes were clarified, setting a clear trajectory for all subsequent investigative and analytical work.

2.2. Phase 2: Comprehensive literature review

A systematic literature review was conducted to establish the theoretical and practical foundation for the proposed SHM for Ghazni, AFG. This review critically

examined core concepts in sustainable hospitality design, with a particular emphasis on EE, renewable energy integration, and low-carbon building strategies, including those aligned with Net-Zero Energy Building (NZEB) principles. Internationally recognized sustainability frameworks and certification systems guidelines were analyzed to distill globally applicable best practices.

The review also investigated a range of international case studies of sustainable hotels, including projects from India [49], China [50], and Indonesia [36], as well as pioneering models such as the Proximity and Bardessono hotels [51]. Recent literature has advanced the integration of BIM with building energy modeling (BEM) for hospitality buildings. Gupta and Sharma [52] demonstrated that BIM coupled with EnergyPlus effectively predicts cooling loads in multi-story hotels, achieving close alignment with observed data while identifying discrepancies arising from idealized occupancy assumptions. Agharid et al. [53] simulated energy-efficient hotel strategies, reporting that double low-emissivity glazing reduced energy consumption by 14.58% and optimized lighting schedules by 8.22%, validating BIM-based parametric analysis as a robust design support tool.

Regarding lifecycle carbon assessment, Capelli et al. [54] analyzed embodied carbon in five Italian hospitality buildings, confirming that structural systems constitute the largest share of upfront emissions and emphasizing the need for localized material databases, a finding particularly relevant to the Afghan context. Keyhani [55] advanced this field by developing an automated BIM-LCA integration using Dynamo and Python scripting, achieving over 98% alignment with manual assessments while reducing analysis time from hours to minutes.

The convergence of vernacular architecture with digital simulation tools has also gained traction. Morcoux et al. [56] integrated rammed-earth construction and solar energy within a BIM-BEM framework to achieve the powerhouse net-zero standard in Andean equatorial climates. Manipadam [57] proposed “Smart Vernacular Pods” combining traditional passive strategies with BIM-based modular workflows and IoT-enabled monitoring. Ramezani and Reza [58] reconstructed vernacular natural ventilation principles in Northern Cyprus using Revit and energy simulations, demonstrating substantial reductions in mechanical cooling demand.

Within the Afghan context, recent studies have begun addressing performance-driven sustainable design. Zamani et al. [59] developed an integrated lifecycle assessment and retrofit model for zero-energy housing in Ghazni Province, demonstrating that combining passive vernacular strategies with PV systems can achieve a 45% operational energy reduction in residential buildings. Their findings validate the applicability of similar integrated frameworks in the same climatic and socio-economic context, reinforcing the methodological approach adopted in this study. A central outcome of this scoping exercise was the identification of a significant research gap: while global standards and case studies provide valuable technical benchmarks, there is a clear lack of methodologies for adapting these principles to the unique socio-economic constraints, cultural values, and extreme climatic conditions of regions such as AFG. This gap underscores the novelty of the present study, which seeks not merely to replicate international models, but to develop a context-sensitive,

climatically resilient, and culturally integrated SHM specifically optimized for Ghazni, AFG.

2.3. Phase 3: Data collection and analysis

To ground the research in the socio-technical realities of Ghazni, AFG, primary data were collected using a convergent mixed-methods approach, integrating quantitative and qualitative instruments to build a comprehensive understanding of the local context. New, firsthand information was gathered through the following three complementary methods designed to capture both measurable trends and nuanced professional insights.

- (1) **Household surveys:** A structured questionnaire was administered to 250 households across Ghazni City's main residential districts. A stratified random sampling strategy was employed, with sample size proportionally allocated based on district population density to ensure representativeness. The sample size was determined using Yamane's formula at a 95% confidence level and a 5% margin of error. Respondents were primarily household heads (72%) or senior family members (28%), with a balanced gender distribution (54% male, 46% female) reflecting local demographics.

The questionnaire was developed through a three-stage process: (1) a literature review of sustainable hospitality and energy behavior surveys, (2) adaptation to the Afghan context through pilot testing with 15 households, and (3) refinement based on feedback to enhance clarity and cultural appropriateness. The instrument comprised four sections: (a) household demographics and housing characteristics, (b) existing energy consumption patterns and building conditions, (c) awareness and perceptions of sustainable hotel features, and (d) willingness to support or utilize sustainable hospitality services. Content validity was established through expert review by three local academics. Reliability was assessed using Cronbach's α , yielding a value of 0.82 for the perception-related items, indicating acceptable internal consistency.

The translation of survey findings into hotel design decisions followed a structured logic. Household responses regarding material preferences (e.g., 48% reported use of local materials) directly informed the selection of compressed earth blocks and clay plaster in the proposed model. Perceptions of energy-saving technologies (94.95% support for solar PV) guided the sizing of on-site renewable energy systems. Preferences for privacy and community spaces (e.g., demand for segregated prayer areas and social event halls) shaped spatial programming and zoning. This alignment ensures that the prototype reflects not only technical optimization but also community expectations and cultural norms.

- (2) **Systematic field observation:** Direct, on-site observational data were collected using structured checklists, photography, GPS mapping, and physical environmental analysis. This method provided contextual evidence of local building typologies, urban morphology, site-specific climatic interactions, and material practices, offering a ground-truth verification of survey and interview data.

(3) Semi-structured expert interviews: In-depth interviews were conducted with a diverse cohort of 24 local specialists, including architects, urban planners, engineers, renewable energy experts, private construction firm representatives, municipal managers, and university professors. Participants were selected via purposive sampling to ensure a wide range of professional expertise and deep familiarity with local constraints and opportunities. Of these, 22 interviews were fully completed and analyzed, providing rich, qualitative insights into practical implementation challenges, the regulatory landscape, material availability, cultural preferences, and perceived pathways for sustainable development.

Interview transcripts were analyzed using a systematic thematic analysis approach following Braun and Clarke’s six-phase framework [60]. The process began with familiarization through repeated reading of all transcripts. Two researchers independently conducted open coding on a subset of five transcripts to generate an initial codebook, identifying 87 discrete codes. Through iterative discussion and consolidation, redundant codes were merged, resulting in 42 distinct codes. These were subsequently grouped into 12 candidate themes, which were refined through four collaborative review sessions to ensure conceptual coherence. The final thematic structure yielded four overarching pillars, Socio-Cultural, Economic, Environmental, and Technical, encompassing 65 integrated design principles.

To ensure coding consistency, inter-coder reliability was assessed on 30% of the transcripts (seven interviews). The percentage agreement reached 86%, and Cohen’s κ was calculated at 0.79, indicating substantial agreement. Discrepancies were resolved through discussion, and the final codebook was applied to all transcripts by the primary researcher, with periodic validation by a second researcher. NVivo 14 software was used to facilitate coding, theme organization, and retrieval of illustrative quotations. A sample coding table (**Table 1**) is provided below to illustrate the analytical progression from raw data to thematic pillars:

Table 1. Illustrative coding progression from expert interview quotations to thematic pillars.

Raw quotation	Initial code	Consolidated code	Theme	Pillar
“The hotel must have completely separate spaces for women and families. This is not negotiable in our culture.”	Gender segregation	Privacy requirement	Cultural norms	Socio-cultural
“We cannot rely on imported materials; we have good clay and stone here, and they keep buildings cool in summer.”	Local materials	Indigenous resources	Material sustainability	Economic
“Orientation matters more than insulation here. The sun is intense, but winter is cold, you need to balance both.”	Solar control	Passive design strategy	Climate responsiveness	Environmental
“Solar panels make sense, but maintenance is a real problem. We need simple systems that local technicians can fix.”	Maintainability	Technical feasibility	System appropriateness	Technical

This analytical process ensured that the resulting four-pillar framework and its 65 constituent principles emerged inductively from expert perspectives rather than being imposed a priori, thereby grounding the subsequent design and simulation phases in locally validated knowledge. The qualitative expert interviews were conducted following a structured four-phase protocol to ensure methodological rigor, depth of insight, and analytical validity, as summarized in the accompanying flowchart (**Figure 3**).



Figure 3. Flowchart of the interview procedure and results [61,62].

The data analysis employed a convergent mixed-methods approach, detailed in **Figure 3**. Quantitative data from household surveys were analyzed using SPSS and Excel to generate descriptive statistics and identify trends. Concurrently, qualitative data from interviews and observations were processed through a rigorous four-stage framework analysis, involving transcription, thematic coding, and interpretation. This integrated process synthesized statistical patterns with deep contextual insights, culminating in a foundational framework of design principles (presented in the Discussion section) that translated local socio-cultural and technical constraints into actionable priorities for subsequent modeling phases.

2.4. Phase 4: Model development and energy analysis

Based on the synthesized framework of design principles established in Phase 3, a conceptual model for the SHM was developed. This phase involved the translation of qualitative socio-technical priorities into a quantifiable, parametric building model for performance evaluation and optimization. The process was executed in three key steps:

- (1) **Digital prototyping:** A detailed 2D and 3D digital prototype of the proposed SHM was created using AutoCAD and Autodesk Revit (BIM) software, incorporating relevant add-ins for enhanced modeling capabilities.
- (2) **Principle implementation:** The context-specific design principles, concerning local materials, cultural integration, passive design, and energy systems, were systematically applied to define the model's geometry, construction assemblies, and technical systems.
- (3) **Parametric energy simulation:** An annual building energy simulation was conducted to evaluate performance. The analysis employed a parametric methodology using Autodesk Revit with the Insight plugin and the Energy Optimization tool, which leverages the EnergyPlus engine (Version 23.1.0). The simulation assessed key performance metrics, including Energy Use Intensity (EUI), operational carbon footprint, and on-site renewable energy generation

potential for a representative calendar year.

To ensure accuracy, site-specific climatic data for Ghazni, AFG, including solar radiation, temperature, and wind patterns, were integrated into the model. This phase produced two comparative digital prototypes: a Traditional Building Model representing local conventional construction, and the Proposed SHM incorporating all derived sustainable design principles.

2.4.1. Simulation framework, site context, and parametric analysis

This phase translated the synthesized design principles and local contextual data into a quantifiable, parametric building model for performance evaluation. The analysis focused on a project situated in the “Nai Qala” area of Ghazni City, AFG (33.29889678955078° N, 67.83448028564453° E), a strategic site characterized by mixed-use urban development, proximity to major infrastructure, and cultural landmarks, providing a realistic test case.

The energy analysis employed a parametric methodology using Autodesk Revit (BIM) with the Insight plugin and Energy Optimization tool, leveraging the EnergyPlus engine (Version 23.1.0). Site-specific climatic data were integrated via Revit’s Internet Mapping Service, with weather data sourced from the nearest station (0.16 km away) to ensure accuracy. An annual simulation evaluated both a traditional building typology and the proposed SHM against key performance metrics: EUI, carbon footprint, and renewable energy generation potential. The simulation parameters were defined as follows: heating setpoint 21 °C, cooling setpoint 24 °C, occupancy density 0.02 persons/m², equipment loads 8 W/m², lighting load 5 W/m², and infiltration rate 0.5 Air Changes per Hour (ACH). Heating, Ventilation, and Air Conditioning (HVAC) system efficiency was modeled with a Coefficient of Performance (COP) of 3.2 for cooling and thermal efficiency of 85% for heating, reflecting locally available system specifications.

While EnergyPlus is a validated simulation engine widely employed in building performance research, several inherent limitations should be acknowledged. First, the software assumes idealized occupancy and operational schedules, which may not fully capture behavioral variability in real-world hotel operations. Second, the thermal performance of locally sourced materials relies on literature-derived values that may differ from actual site-specific conditions due to supply chain inconsistencies. Third, the simulation does not account for partial load inefficiencies or system degradation over time. These limitations are acceptable for a comparative analysis between typologies, as they apply consistently to both models, allowing for robust relative performance assessment rather than absolute prediction.

2.4.2. Building model specifications and envelope optimization

Two distinct digital models were developed and analyzed to quantify the performance impact of the proposed sustainable interventions:

- (1) Traditional building model:** This model represents prevalent local construction practices in Ghazni, characterized by thermally inefficient, non-insulated materials. Key elements include 25 cm weak masonry walls without insulation, an 18 cm uninsulated concrete roof slab, and single-glazed windows with metal frames. This assembly results in poor thermal performance and significant

undesired heat transfer.

- (2) **Proposed SHM:** Developed by applying the context-derived design principles, this model is optimized for high thermal efficiency and cultural resonance. Key interventions include: walls constructed with compressed earth blocks and clay plaster for thermal mass and local material use; an intensive green roof system for natural insulation and reduced heat gain; and triple-glazed windows with PVC frames to minimize thermal bridging. These specifications fundamentally enhance the building’s thermal performance, energy conservation, and indoor environmental quality, representing critical steps towards a viable, sustainable hotel complex (**Table 2**).

Table 2. Building envelope specifications and optimized characteristics for the traditional and proposed models.

Model option		Traditional hotel building		Proposed SHM	
Building element	Thickens	Materials	Thickens	Materials	
Wall	25 cm	Two-side paint. Two-side plaster. Common brick.	45 cm	EIFS, Exterior Insulation. Common Brick. Insulation XPS. Mud block. Vapor Retarder. Clay plaster.	
Roof	18 cm	PCC 3 cm. Traditional plastic. RCC 12 cm. Plaster 1.5 cm.	63 cm	Intensive vegetation. Vegetation substrate. Geotextile filter fabric-TS 10. Accumulation and drainage mat-DELTA. Separation and diffusion mat-DELTA. Thermal insulation XPS 300 kN/m ² . Anti-root waterproofing membrane. Base waterproofing membrane. Substrate soil. Concrete slab.	
Exterior Window	4 mm	single glazing. Metal frame.	6 mm	Triple glazing - low-E/low-E/clear. PVC frame.	
Exterior Door	4 mm	single glazing. Metal frame.	6 mm	Triple glazing - low-E/low-E/clear. PVC frame.	

The parametric simulation framework was used to evaluate and optimize the building envelope, with a particular focus on the strategic adjustment of the WWR and orientation-specific glazing to balance daylighting, solar heat gain, and thermal losses in response to Ghazni’s climate.

2.4.3. Building envelope optimization: WWR

A critical focus of the parametric energy analysis was the climate-responsive optimization of the building envelope, specifically the strategic adjustment of the WWR by orientation. The proposed SHM demonstrates a significant departure from the conventional typology. The analysis reveals a substantial reduction in total glazing area: from 865.88 m² to 367.73 m². Consequently, the Gross WWR decreased from 22.10% to 19.63%.

More importantly, the proposed design strategically rebalances glazing distribution per facade to respond to Ghazni’s solar path. The most substantial

reduction occurred on the East facade, where the WWR was lowered from 23.93% to 17.80% to minimize morning solar heat gain. A strategic increase was applied to the South facade, raising the WWR from 29.43% to 29.65% to maximize beneficial passive solar heating in winter. Reductions were also implemented on the North facade (from 13.79% to 11.88%) and the West facade (from 21.63% to 16.39%) to control thermal losses and unwanted afternoon heat gain, respectively. This orientation-specific optimization minimizes thermal waste while strategically harnessing passive solar energy, leading to a substantial improvement in overall energy performance and occupant comfort (Table 3).

Table 3. WWR analysis by orientation for the traditional and proposed models.

Model option	Direction of the windows/azimuth angle	Gross wall area [m ²]	Window opening area [m ²]	Gross WWR [%]
Traditional	North (315° to 45°)	1,223.40	168.72	13.79
	East (45° to 135°)	704.49	168.55	23.93
	South (135° to 225°)	1,258.18	370.25	29.43
	West (225° to 315°)	732.21	158.26	21.63
	Total	3,918.29	865.88	22.10
Proposed	North (315° to 45°)	1,114.54	132.40	11.88
	East (45° to 135°)	601.86	107.15	17.80
	South (135° to 225°)	1,171.52	347.33	29.65
	West (225° to 315°)	615.19	100.85	16.39
	Total	3,503.11	367.73	19.63

2.4.4. Model synthesis and visual representation

The culmination of the parametric design process resulted in two fully developed digital energy models. The Traditional Hotel Model reflects the prevalent, thermally inefficient construction practices in Ghazni. In contrast, the Proposed SHM embodies the integrated, climate-responsive, and culturally attuned design principles derived from this study's analytical phases. Digital prototypes of both models were generated, incorporating the detailed envelope specifications and optimized WWR strategies, as visually summarized in Figure 4. These calibrated models served as the direct input for the comparative annual energy simulation, the results of which form the core findings discussed in the subsequent section.

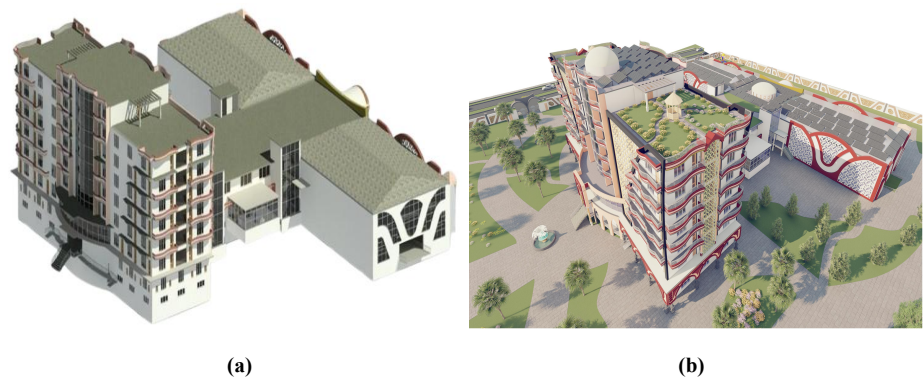


Figure 4. Energy analysis models: (a) Traditional hotel typology; (b) Proposed SHM prototype.

2.5. Phase 5: Analysis of outcomes and comparative performance assessment

This final phase synthesizes all analytical findings into a tangible architectural proposal and assesses its performance through rigorous simulation. A comprehensive SHM for Ghazni was developed by translating the established design principles into integrated architectural and engineering features. These include the incorporation of solar energy systems, the prioritized use of local construction materials, a design optimized for natural ventilation and daylighting through strategic window placement and transparent roofs, and integrated systems for waste management and water recycling. The physical form and aesthetics were designed to harmonize with the local environment and reflect Ghazni's cultural and Islamic identity. The final design was visualized and detailed using industry-standard software (AutoCAD, Revit BIM, SketchUp, Lumion, Photoshop).

This proposed SHM was translated into a detailed digital prototype to undergo a rigorous comparative performance analysis against a conventional building typology. The energy simulation outputs, specifically annual EUI, carbon emissions, and renewable energy generation potential, were systematically compared to quantify the performance improvements attributable to the design interventions. These comparative results form the primary evidence base for validating the efficacy of the design framework, discussing the performance gap between building typologies, and evaluating the model's alignment with both global sustainability benchmarks and local socio-technical feasibility. The outcomes directly inform the final conclusions and provide actionable recommendations for implementing context-sensitive, climate-resilient architecture in Ghazni and analogous regions.

The reliability of the simulation results is ensured through the use of validated industry-standard software: Autodesk Revit (BIM) with the Insight plugin, which leverages the EnergyPlus calculation engine, a tool whose methodologies are benchmarked against empirical data and peer-reviewed standards [63–65]. The simulation was conducted in accordance with established testing protocols [66–68]. To ensure accuracy, all model inputs were calibrated with localized parameters, including Ghazni's site-specific climatic data, precise geographical coordinates, and the measured thermal properties of local construction materials. The analysis operated under standard simulation assumptions (e.g., CIE clear sky conditions), which, while necessary for a controlled comparative study, acknowledge a limitation regarding real-world variability. Therefore, the results are presented with high confidence as a robust, comparative performance assessment between the conventional and proposed typologies, rather than as an absolute prediction of energy consumption, providing a scientifically sound evaluation of the achievable performance gains. To strengthen the comparative basis, simulation outputs were analyzed using relative performance metrics, including percentage reduction in EUI and operational carbon between the traditional and proposed models. Sensitivity analysis was conducted on key parameters, WWR, insulation thickness, and glazing type, to evaluate their marginal contribution to overall performance. This approach enables identification of the most impactful design interventions and supports the generalizability of findings beyond the

specific case.

3. Results and discussion

3.1. Analysis of household survey data

The household survey provides critical insights into the prevailing public understanding of sustainable hospitality and the operational status of existing hotels in Ghazni, revealing significant gaps in awareness, infrastructure, and sustainable practices that directly inform the necessity for a context-sensitive SHM.

A foundational finding is the fragmented public perception of the sustainability concept itself, as detailed in **Figure 5a**. A majority (74%) of respondents viewed a ‘sustainable hotel’ as a broad, general concept potentially encompassing environmental, social, and economic responsibility. However, a deeper breakdown reveals a lack of consensus on its specific components: 11% associated it primarily with social responsibility (e.g., community welfare, employee rights), 9% with environmental protection, and only 6% explicitly linked it to energy efficiency. This indicates that while sustainability is recognized as a positive value, its precise technical and practical dimensions remain ambiguous to the general public. This knowledge gap establishes a foundational barrier to both demand for and acceptance of advanced sustainable hospitality infrastructure.

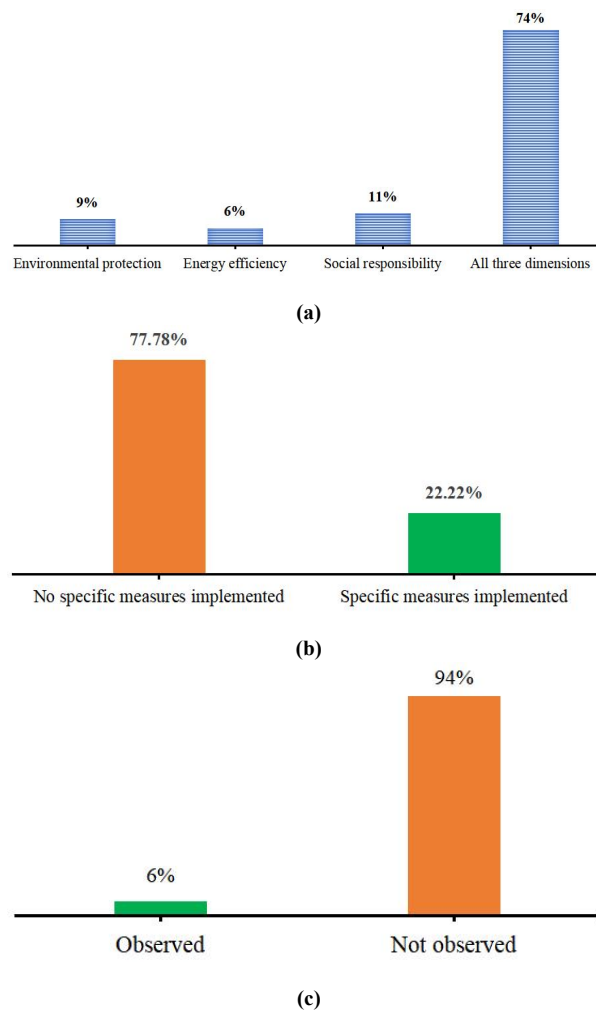


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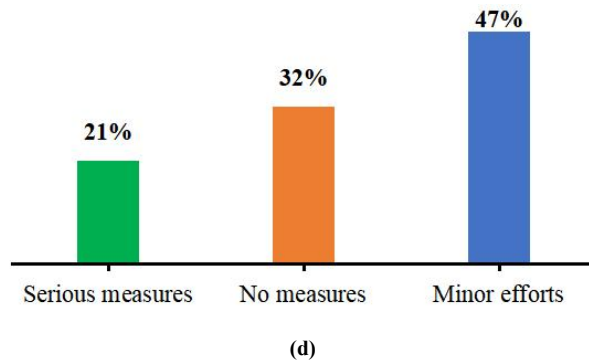


Figure 5. Household survey results in Ghazni: (a) Public perception of sustainability; (b) Implementation of energy-efficiency measures; (c) Presence of water-recycling systems in hotels; (d) Adoption of pollution reduction and waste-management measures by hotels.

This ambiguity is mirrored in the perceived state of existing hotel practices. The survey results point to a pronounced deficit in operational sustainability within Ghazni’s current hotel sector, as shown in **Figure 5b**. An overwhelming 77.78% of respondents believe that local hotels have implemented no specific EE measures, with only 22.22% perceiving their existence. This perception suggests either a complete lack of energy-saving interventions or a failure of hotels to effectively communicate and demonstrate such measures, both of which highlight a critical area for improvement. This absence of perceived energy conservation aligns with a severe shortfall in water management, where 94% of respondents reported observing no systematic water recycling systems in local hotels (**Figure 5c**).

Finally, the survey assessed perceptions of pollution control and waste management. The results present a mixed yet concerning picture (**Figure 5d**). While 21% of respondents acknowledged the existence of serious measures in these areas, a plurality of 47% reported only “minor efforts.” Combined with the 26% who observed no measures and 6% who categorically denied their existence, these findings indicate that comprehensive, systematic waste and pollution management protocols are not widely implemented or visibly effective in Ghazni’s hotels.

In summary, the household survey data collectively paint a picture of a hospitality sector where public awareness of sustainability is broad but imprecise, and tangible, high-impact sustainable practices in energy, water, and waste management, are largely absent or imperceptible. This socio-technical context underscores the urgent need for the proposed SHM not only as a physical prototype but also as an educational and practical benchmark to elevate both industry standards and public expectations for sustainable development in Ghazni.

The survey further investigated practical aspects of construction and social services within the current hotel sector, along with public priorities for a sustainable hotel’s features and perceived benefits.

Public perception regarding the use of indigenous building materials in Ghazni’s hotels was nearly evenly divided. As shown in **Figure 6a**, 48% of respondents reported the use of local materials in hotel construction, while 52% did not observe their application. This indicates a significant missed opportunity, as utilizing locally sourced materials is a cornerstone of sustainable construction, reducing embodied

carbon, supporting the local economy, and enhancing cultural continuity. Similarly, the provision of dedicated facilities for social and religious events was deemed inconsistent. As indicated in **Figure 6b**, 49% of respondents acknowledged the existence of such dedicated measures in hotels, compared to 51% who did not, highlighting a sector where the integration of vital community and cultural services is not yet standardized.

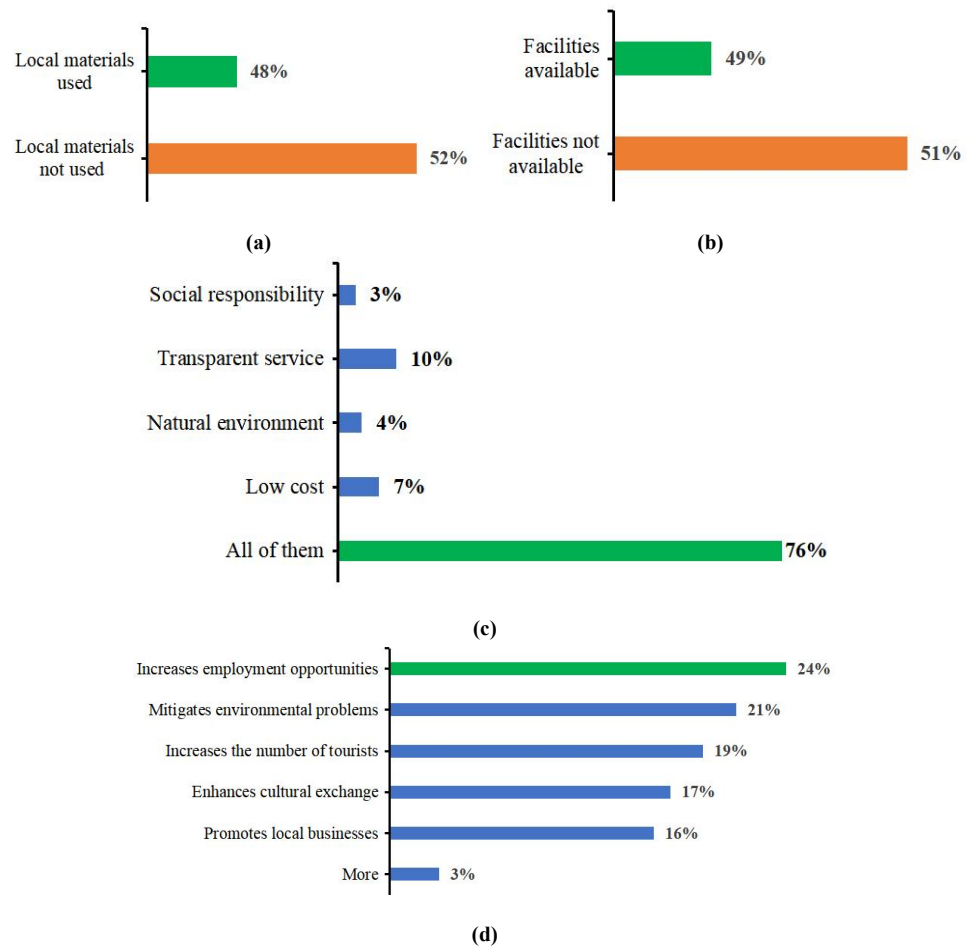


Figure 6. Household survey results in Ghazni: **(a)** Use of local construction materials and social amenities; **(b)** Availability of hotel facilities for social events; **(c)** Prioritized characteristics of a sustainable hotel; **(d)** Perceived impacts of constructing a sustainable hotel in Ghazni.

When asked to prioritize specific features of a sustainable hotel, respondents overwhelmingly valued the overall concept of sustainability itself. A significant 76% assigned this the highest priority (**Figure 6c**). In contrast, granular aspects received markedly less emphasis: transparent services (10%), affordable pricing (7%), a natural environment (4%), and social responsibility (3%). This disparity reinforces the earlier finding of a broad but non-specific public understanding of sustainability. It suggests that while there is strong foundational support for the idea of a sustainable hotel, detailed public education is required to build demand for its specific environmental and social-technical components.

The survey concluded by gauging public expectations for the potential impact of building a sustainable hotel in Ghazni. The results, presented in **Figure 6d**, reveal a strong consensus on multi-faceted positive outcomes. The most anticipated benefit was

job creation (24%), followed by reduction of environmental problems (21%), increase in tourist numbers (19%), growth of local businesses (16%), and enhancement of cultural exchange (17%). This clear alignment of perceived economic, environmental, and socio-cultural benefits demonstrates strong public endorsement for the proposed SHM. It indicates that the community views such a development not merely as an infrastructural project but as a catalyst for comprehensive regional progress, validating the integrated approach taken in this research.

Beyond general awareness, the survey yielded critical insights into specific guest priorities and public support for key sustainable building technologies. When asked to identify the most important factors for hotel accommodation, respondents prioritized cleanliness (25%) and security (20%) as paramount (**Figure 7a**). This underscores that foundational service quality is a non-negotiable prerequisite for guest satisfaction. Significantly, proximity to nature (18%) and eco-friendly services (17%) also ranked highly, indicating a clear public appetite for hospitality experiences that offer environmental quality and responsibility, provided core standards of comfort and safety are met.

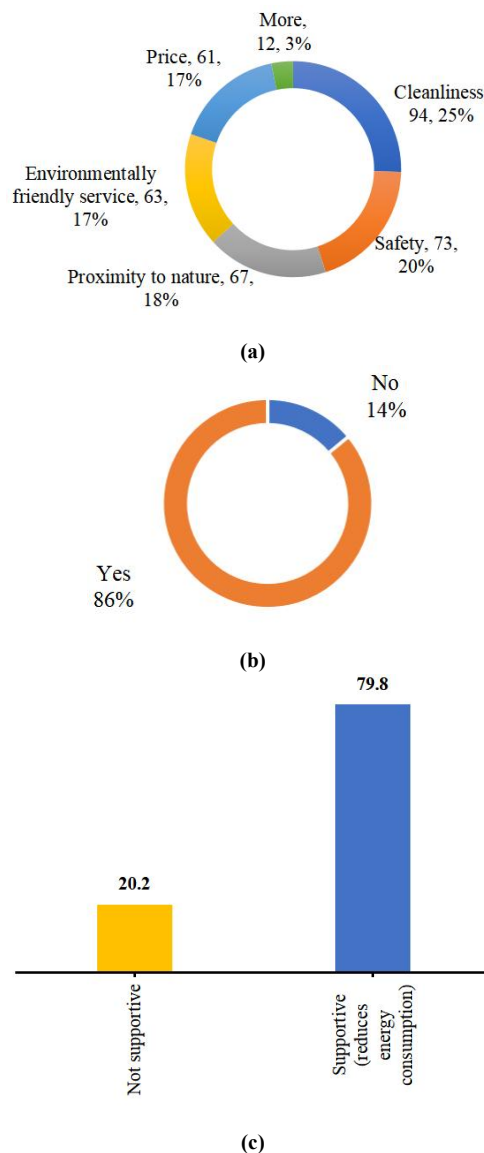


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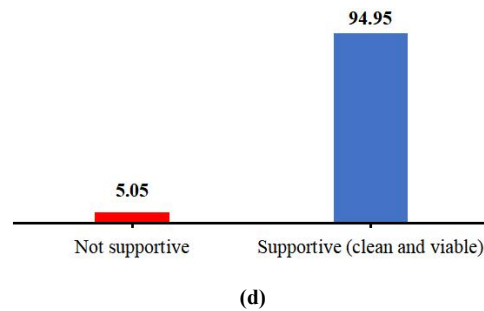


Figure 7. Household survey results in Ghazni: **(a)** Key factors influencing hotel accommodation choice; **(b)** Perceived sustainability of using PVC doors and windows; **(c)** Perceived sustainability benefits of increased wall thickness; **(d)** Perceived sustainability impacts of using solar energy in hotels.

Public support for the integration of specific sustainable building features was overwhelmingly positive. There was strong endorsement for the use of PVC windows and doors, with 86% of respondents believing they would play a crucial role in establishing hotel sustainability, citing benefits in energy insulation and durability (**Figure 7b**). Similarly, increasing wall thickness for better thermal performance was supported by 79.80% of respondents who recognized its potential to reduce energy consumption (**Figure 7c**). Most conclusively, the integration of solar energy systems received near-unanimous backing from 94.95% of respondents (**Figure 7d**), highlighting a clear public recognition of solar power as a clean, viable, and essential component of a sustainable hotel for Ghazni's sunny climate.

This data reveals a vital public consensus: the local community not only supports the concept of a sustainable hotel but also specifically endorses the core technical interventions, improved building envelope performance, and renewable energy integration, that form the foundation of the proposed SHM. This alignment between technical design solutions and public acceptance significantly strengthens the feasibility and potential success of implementing such a model in Ghazni.

3.2. Analysis of expert interviews: Synthesis of a contextual design framework

This phase sought to establish a foundational design philosophy for the Ghazni SHM by extracting and synthesizing expert insights from the local socio-technical ecosystem. In-depth semi-structured interviews were conducted with 24 professionals and policymakers from government (municipal and urban planning departments), academia (e.g., Kabul University, Kabul Polytechnic University, Ghazni University, Paktia University, etc.), and the private sector (engineering firms, construction specialists). Participants were purposively selected for their expertise in sustainable engineering, zero-energy buildings, climate adaptation, and Islamic architectural values. The interviews focused on core themes: climate adaptation, energy efficiency, local material use, socio-cultural interaction, and tourist needs. A rigorous thematic analysis method was employed, involving transcription, initial code identification, theme organization, and thematic interpretation, to ensure a systematic and valid extraction of design principles.

3.2.1. Foundational principles for a Ghazni-specific SHM

The expert discourse converged on a holistic definition of a sustainable hotel as a structure that establishes a vital balance between four interdependent pillars: environmental stewardship, economic viability, socio-cultural harmony, and technical-engineering integrity. This is not merely an additive checklist but an integrated system. For Ghazni, this translates into a model where resource efficiency is inextricably linked with cultural respect and economic pragmatism. The proposed SHM is envisioned not as an imported prototype but as an organic component of Ghazni’s urban fabric, its climate, heritage, and community.

3.2.2. Critical design priorities and principles

The thematic analysis yielded a comprehensive, context-driven set of principles across four domains (Figure 8).



Figure 8. A four-pillar, locally adapted 65 design principles framework for achieving SHM in Ghazni, developed based on thematic analysis of 22 expert interviews.

(1) Socio-cultural and Islamic design principles: A paramount, non-negotiable

principle is the rigorous respect for privacy “Mahramiyat”, mandating the design of fully segregated and private spaces for women and families across all functions, from dining halls to social event venues. The architectural identity must actively reflect Ghazni’s status as a historical capital of Islamic culture. This is to be achieved by incorporating traditional Afghan-Islamic elements such as central courtyards “Hayat”, arches “Qaws”, domes, intricate ornamentation (calligraphy, tilework), and the use of vernacular spatial sequences. Furthermore, the hotel must function as a community asset by providing dedicated multi-functional spaces for social gatherings “majalis” and facilitating religious observance, including Qibla-oriented prayer rooms on every guest floor.

- (2) **Economic and material sustainability principles:** True economic sustainability was defined as maximizing value for the local economy throughout the building’s lifecycle. This necessitates a primary focus on utilizing indigenous, low-embodied-energy materials, such as compressed earth blocks, local stone, lime, and timber, to minimize transport costs, support local industries, and ensure inherent climatic compatibility. The SHM’s development and operation should be structured to maximize local employment opportunities, from construction labor to skilled management. Experts emphasized life-cycle cost efficiency, prioritizing durable, low-maintenance designs and systems that yield long-term operational savings over short-term capital cost minimization.
- (3) **Environmental and climatic responsiveness principles:** Given Ghazni’s arid continental climate with hot summers and cold winters, a passive-first design ethos is critical. This involves strategic building orientation and the optimized, orientation-specific control of WWR to maximize beneficial solar gain in winter while minimizing undesirable heat gain in summer. Designs must promote natural cross-ventilation, potentially leveraging traditional passive cooling strategies. There was unequivocal expert consensus on integrating on-site solar PV and thermal systems as the primary renewable energy source. A closed-loop resource management strategy is essential, incorporating systems for rainwater harvesting, greywater recycling, and comprehensive waste segregation for composting and recycling, thereby drastically reducing the hotel’s demand on municipal water and waste infrastructure.
- (4) **Technical and infrastructural principles:** Experts acknowledged the pragmatic challenges of Ghazni’s urban context, including unreliable water and power supply and a lack of stringent, updated building codes. Therefore, the SHM’s design must be resilient and adaptable, featuring redundant systems and robust, low-tech solutions where appropriate. The recommended technological approach advocates for a hybrid model: leveraging simple, proven passive techniques augmented by targeted, high-efficiency active systems (e.g., LED lighting, high-efficiency HVAC) rather than complex, maintenance-heavy technologies unsuited to the local operational capacity.

3.2.3. Synthesis: An integrated design framework for the Ghazni SHM

The synthesis of these expert insights culminates in an integrated, four-pillar design framework that rejects a siloed approach to sustainability. This framework

posits that Environmental Resilience, Socio-Cultural Harmony, Economic Viability, and Technical Feasibility are deeply interconnected (**Figure 8**). In this model, EE is not a standalone technical goal but emerges naturally from culturally resonant building forms and material choices. Economic sustainability is driven by local supply chains and job creation, not just operational savings. Social acceptance is engineered through a foundational respect for religious and community norms. This holistic, context-sensitive framework provides the direct conceptual and operational blueprint for the subsequent phases of parametric modeling and performance optimization. It ensures the final SHM proposal is not only a high-performance building by international standards but, more importantly, a culturally embedded, economically generative, and replicable model for sustainable development in Ghazni and analogous regions.

In **Figure 9**, the four pillars are presented as interdependent components: Socio-Cultural and Islamic (top), Economic and Material Sustainability (right), Environmental and Climatic Responsiveness (bottom), and Technical and Infrastructural (left). Arrows indicate directional dependencies: cultural acceptance enables local employment and material sourcing; economic viability determines appropriate technology selection; technical feasibility drives environmental performance; and environmental quality enhances community wellbeing and cultural pride. Feedback loops illustrate synergistic interactions, such as environmental performance attracting tourism, which stimulates economic growth, which in turn funds cultural preservation. This integrated structure emphasizes that authentic sustainability emerges from the synergistic interaction of all four pillars rather than from isolated interventions.

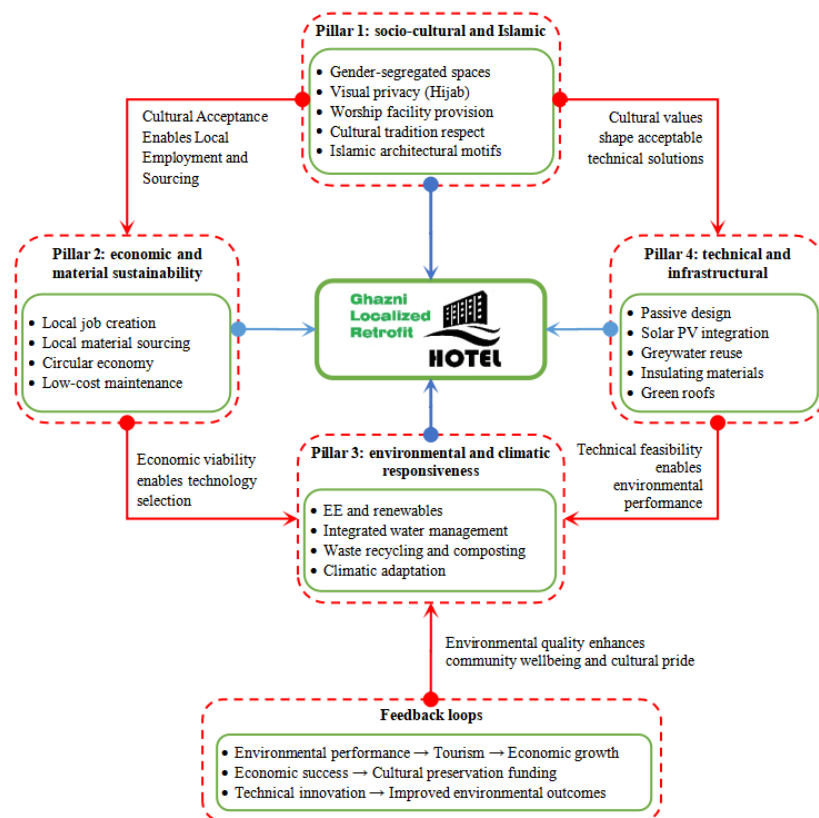


Figure 9. Interconnected four-pillar framework for SHM in Ghazni. Arrows indicate mutual dependencies and feedback loops.

The research establishes that sustainable hotel design transcends mere technical and architectural solutions. It represents a holistic, value-driven, and multidimensional philosophy that must integrate with the climatic, cultural, economic, religious, and social fabric of its context. Grounded in Ghazni City's environmental realities, cultural heritage, Islamic principles, social imperatives, economic potential, and technical capabilities, this study proposes an integrated design framework that aligns with global sustainability benchmarks while authentically embodying local specificity. Structured upon four interdependent pillars, Environmental, Socio-Cultural, Economic, and Technical, this framework provides a professional scaffold for engineers while advocating for a synergistic relationship between people, place, nature, and values. It thereby imbues the hotel complex's physical structure not only with architectural form but with deeper meaning, reflecting social identity, religious ethics, economic equity, and environmental stewardship.

Consequently, the framework delineates a shared vision, common purpose, and collective responsibility among stakeholders, including engineers, investors, policymakers, and end-users. As such, it functions not merely as a theoretical model, but as a practical, adaptive, and enduring guideline for sustainable construction. Ultimately, this integrated approach ensures that the Ghazni Sustainable Hotel Complex serves as both an architectural landmark and a replicable prototype, socially responsive, economically sound, ecologically regenerative, and technologically proficient, for sustainable development in arid regions.

3.3. Comparative energy simulation: Traditional vs. Proposed SHM results

3.3.1. Energy use intensity (EUI) and end-use analysis

A comparative analysis of energy simulation results between the Traditional and Proposed SHM reveals significant performance improvements across all major end-use categories. The data, summarized in the integrated **Table 4** below, quantifies the impact of sustainable design strategies, including enhanced thermal insulation, passive design, high-efficiency HVAC systems, energy-efficient lighting (LEDs), and advanced appliances, on the building's total energy demand.

The proposed SHM achieves substantial savings in both space conditioning loads, which are dominant in Ghazni's climate. The most pronounced reduction is observed in cooling energy demand, which decreases by 20.66% (205,750 kWh). This highlights the particular effectiveness of the proposed interventions in mitigating solar heat gain and improving thermal comfort passively. Heating demand also sees a 4.07% reduction (22,825 kWh). Consequently, the total site energy consumption is reduced by 14.68% (228,575 kWh), decreasing from 1,556,414 kWh to 1,327,839 kWh.

Analyzing consumption by fuel type provides further insight into system efficiency. Electricity use, powering lighting, equipment, and a portion of cooling, decreases by 13.34% (223,050 kWh). When examining specific electrical end-uses, interior lighting and interior equipment loads each see reductions of 13.34%, directly attributable to the specification of high-efficiency luminaires, daylighting strategies, and Energy Star-rated appliances. In terms of primary energy, the total source

energy requirement is reduced by 14.36% (1,002,981 kWh), underscoring the holistic efficiency gains that reduce demand across the entire energy supply chain.

Table 4. Comparative energy performance analysis of traditional vs. proposed SHM.

Metric	Category	Traditional building (kWh)	Proposed SHM (kWh)	Absolute saving (kWh)	Reduction (%)
End-Use Consumption	Heating	560,533	537,708	22,825	4.07
	Cooling	995,881	790,131	205,750	20.66
	Total Site Energy ¹	1,556,414	1,327,839	228,575	14.68
Source Energy by Fuel	Electricity	1,671,855	1,448,805	223,050	13.34
	Heating Fuel	1,912,619	1,834,737	77,882	4.07
	Cooling Fuel	3,398,086	2,696,037	702,049	20.66
	Total Source Energy ²	6,982,560	5,979,579	1,002,981	14.36
Electricity Use Intensity	Interior Lighting	181,472	157,261	24,211	13.34
	Interior Equipment	308,500	267,342	41,158	13.34
	Lighting + Equipment Subtotal	489,972	424,603	65,369	13.34
Total EUI	Annual EUI (kWh/m ²)	359.97	348.11	11.86	3.3

Note: ¹Total Site Energy represents the energy consumed at the building site. ²Total Source Energy includes the raw fuel required to generate and deliver that energy to the site, accounting for generation and transmission losses, and is a more complete measure of environmental impact.

These results conclusively demonstrate the proposed integrated design framework. The annual EUI is reduced from (359.97 to 348.11) kWh/m², representing a 3.3% decrease compared to the conventional design (Table 4), resulting in effectively decoupling hotel operation from high energy demand. The framework establishes a robust, quantifiable benchmark for sustainable hospitality architecture in arid regions, proving that climate-responsive, socio-culturally attuned design can yield significant and measurable environmental and economic benefits.

A comparative analysis of energy simulation results between the Traditional and Proposed SHM demonstrates a significant and consistent improvement in energy performance across all major end-use categories, as detailed in the integrated Table 4 and the comparative monthly profiles in Table 5.

Table 5. Comparative monthly electricity consumption of interior lighting and interior equipment for the Proposed SHM versus the Traditional building baseline.

Month	Interior lighting consumption		Interior equipment consumption	
	Traditional-lighting (kWh)	Proposed SHM-lighting (kWh)	Traditional-equipment (kWh)	Proposed SHM-equipment (kWh)
Jan	15,412.61	13,356	26,201.47	22,705.2
Feb	13,921.08	12,063.2	21,366.8	20,508.47
Mar	15,412.61	13,356.4	26,201.47	22,705.2
Apr	14,915.4	12,925.5	25,356.3	21,973.36
May	15,412.7	13,356.4	26,201.47	22,705.2
Jun	14,915.4	12,925.5	25,356.3	21,973.36
Jul	15,412.7	11,335.4	26,201.47	22,705.2
Aug	15,412.61	13,356.4	26,201.47	22,705.81
Sep	14,915.4	12,925.5	25,356.3	21,973.36
Oct	15,412.7	13,356.4	26,201.47	22,705.2
Nov	14,915.4	12,925.5	25,356.3	21,973.36
Dec	15,412.7	13,356.4	26,201.47	22,705.2

The results presented above reflect the cumulative performance of the proposed SHM, which integrates multiple design interventions simultaneously, including

envelope upgrades (walls, roof, glazing), optimized WWR, high-efficiency HVAC, LED lighting, and on-site PV generation. As such, the reported energy and carbon reductions represent the synergistic effect of the full design package rather than the isolated contribution of any single strategy. This integrated approach aligns with the study’s objective of evaluating a holistic, context-specific model.

3.3.2. Embodied and operational carbon footprint analysis

A lifecycle carbon assessment demonstrates the transformative potential of the proposed SHM framework. As synthesized in **Figure 10** and **Table 6**, the SHM achieves a substantial 73.3% reduction in total carbon emissions compared to a conventional building, driven primarily by an 80.3% reduction in embodied carbon alongside measurable gains in operational efficiency.

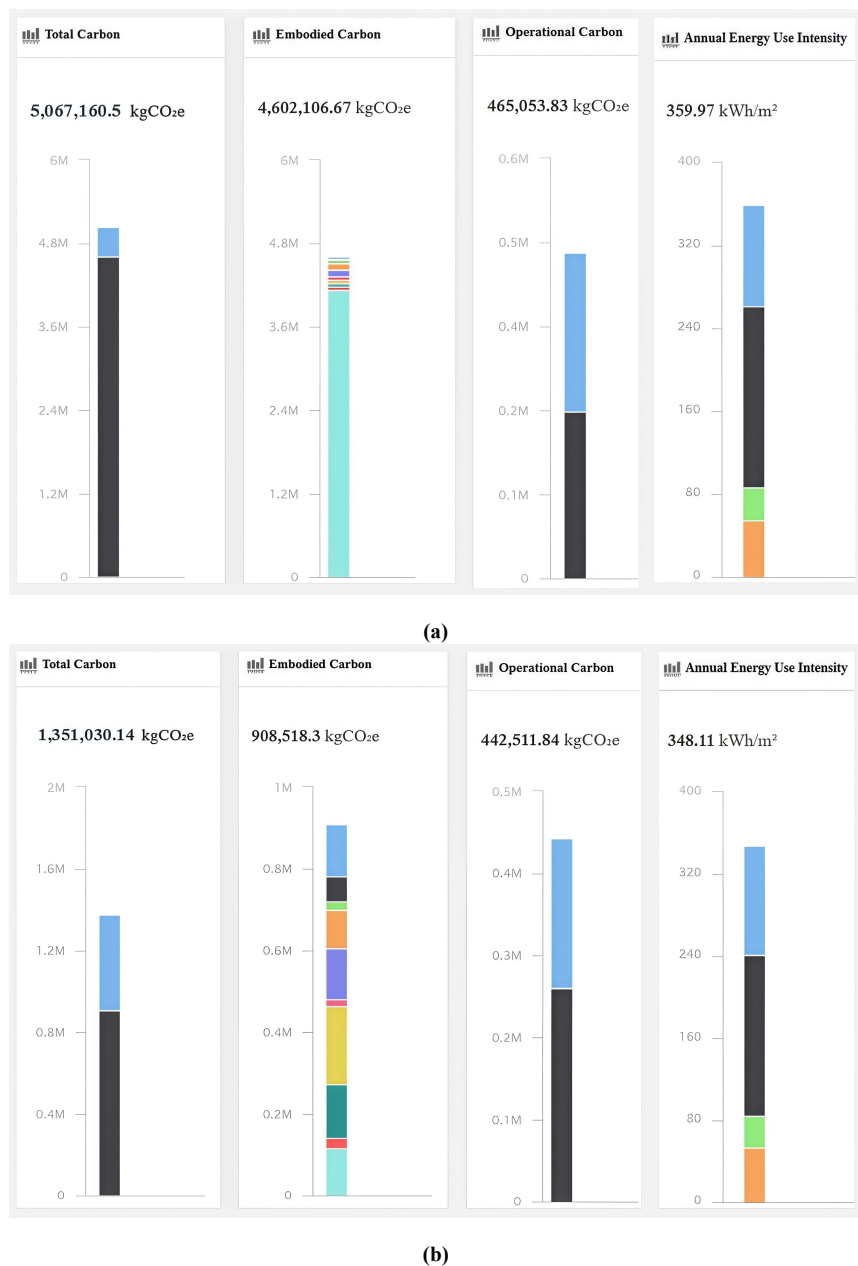


Figure 10. Comparative embodied and operational carbon footprint and annual EUI analysis: (a) Traditional building; (b) Proposed SHM.

Table 6. Comparative analysis of carbon footprint and energy intensity.

Metric	Traditional building	Proposed SHM	Absolute mitigation	Reduction
Total Carbon Emissions (kgCO ₂ e)	5,067,160.5	1,351,030.14	3,716,130.36	73.3%
Embodied Carbon (kgCO ₂ e)	4,602,106.67 (90.8% of total)	908,518.3 (67.2% of total)	3,693,588.37	80.3%
Operational Carbon (kgCO ₂ e)	465,053.83 (9.2% of total)	442,511.84 (32.8% of total)	22,541.99	4.8%
Annual EUI (kWh/m ²)	359.97	348.11	11.86	3.3%

For the traditional building baseline, total emissions amount to 5,067,160.5 kgCO₂e. This footprint is overwhelmingly dominated by embodied carbon from material production and construction, which constitutes 4,602,106.67 kgCO₂e (90.8% of the total). Operational carbon, resulting from an annual EUI of 359.97 kWh/m², contributes 465,053.83 kgCO₂e (9.2%).

The proposed SHM design yields a total carbon footprint of 1,351,030.14 kgCO₂e, mitigating 3,716,130.36 kgCO₂e. The cornerstone of this achievement is the dramatic decrease in embodied carbon to 908,518.30 kgCO₂e, validating the framework's emphasis on local, sustainable material sourcing. Operational carbon is also reduced by 4.8% to 442,511.84 kgCO₂e, accompanied by a 3.3% decrease in EUI to 348.11 kWh/m², reflecting improvements from passive design and energy-efficient systems. Consequently, the share of operational carbon within the total footprint increases to 32.8%, shifting the primary environmental impact to a phase amenable to direct mitigation through on-site renewable energy integration.

The color coding in **Figure 10** follows the default Autodesk Insight dashboard classification within the Revit ecosystem, where each color corresponds to a distinct building assembly: light blue (external walls), dark gray (columns), light green (underground walls), orange (underground floors), purple (roofs), red (foundations), pink (slabs), yellow (raised floors), teal (interior walls), and cyan (windows/openings). This classification standardizes the presentation of embodied carbon contributions by assembly type, facilitating clear comparative assessment between the traditional and proposed models. The accompanying legend ensures interpretability for readers unfamiliar with the software interface.

Collectively, these results establish a critical paradigm for sustainable construction in arid climates like Ghazni: the most impactful decarbonization strategy lies in the radical optimization of embodied carbon through informed local material selection and circular economy principles, as mandated by the framework's Economic and Material Sustainability pillar (as shown in **Figure 8**). The demonstrated 80.3% reduction in embodied carbon validates this approach, while the concurrent reductions in operational carbon and EUI affirm the synergistic role of passive design and EE measures from the environmental and technical pillars. The fundamental shift in the embodied-to-operational carbon ratio represents a successful rebalancing of the building's lifecycle impact. This strategic rebalancing intentionally positions the now-dominant operational carbon for effective abatement through on-site renewable energy integration, a core tenet of the integrated design framework that ensures holistic, long-term sustainability.

The results presented above substantiate the theoretical four-pillar framework (**Figure 8**) through quantifiable evidence. The Environmental pillar is validated by

the 20.66% reduction in cooling demand and 73.3% total carbon mitigation. The Socio-Cultural pillar, though not directly measurable in energy terms, informed envelope optimization through privacy considerations and courtyard-driven massing, which indirectly contributed to thermal performance. The Economic pillar is evidenced by the 13.4-year payback period for PV systems and lifecycle cost savings from reduced operational energy. The Technical pillar is operationalized through the successful integration of locally appropriate HVAC specifications and simulation-validated envelope assemblies. This alignment confirms that the framework functions not merely as a conceptual scaffold but as a predictive and actionable design tool.

It is important to note that the performance improvements demonstrated in this study result from the combined application of multiple passive and active strategies. While individual measures, such as improved insulation or PV integration, each contribute to overall savings, the reported reductions (14.68% site energy, 73.3% carbon) reflect the synergistic effect of the integrated design package. Future research could employ sensitivity or parametric analysis to isolate the marginal contribution of individual components, which would further inform optimization and cost-benefit trade-offs.

3.3.3. Analytical assessment of PV solar energy production for the proposed SHM

To operationalize the framework's renewable energy principle, the solar energy potential of the proposed SHM was quantified using an advanced solar radiation model in Autodesk Revit (**Figure 11**). The analysis, configured for Ghazni's latitude (78° altitude, 12° tilt), identified optimal panel placement on high-irradiance roof areas (highlighted in yellow/orange on the irradiance map), receiving an average of 278 kWh/m²/year.

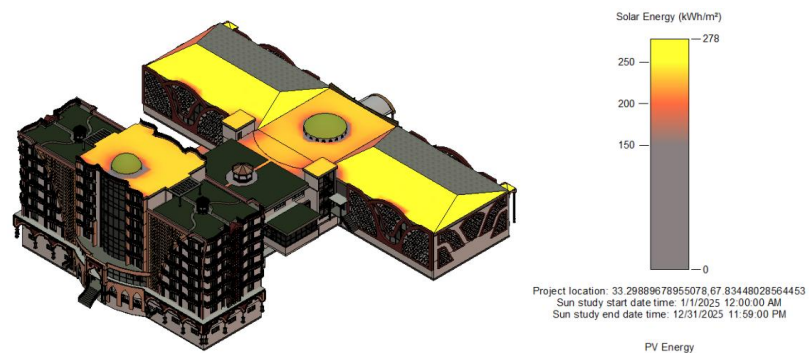


Figure 11. Annual solar radiation and PV energy potential at the project site in Ghazni Province, indicating conditions favorable for SHM performance.

The simulation determined a total effective PV area of 1,890 m², capable of generating approximately 389,296 kWh annually. This output satisfies 91.6% of the hotel's estimated annual electricity demand (424,603 kWh), with an 8.4% deficit (35,307 kWh) to be supplemented by the grid. The system delivers direct annual financial savings of \$58,394 and offsets a significant volume of operational carbon emissions, contributing directly to the 73.3% total carbon reduction reported in Subsection 3.3.2. The calculated capital payback period is 13.4 years, confirming long-term economic viability alongside environmental performance.

The reliability of these findings is anchored in the use of standardized building performance simulation software (Revit BIM), calibrated with Typical Meteorological Year (TMY) data for Ghazni, which provides a robust and replicable methodological foundation for preliminary assessment. However, it is necessary to acknowledge that real-world performance may vary due to site-specific microclimatic factors, long-term equipment efficiency degradation, and operational practices, indicating a scope for future validation through post-occupancy monitoring.

Regarding generalization, while the quantified energy yields and financial payback are specific to Ghazni's high solar irradiance and local economic context, the core methodological contribution, the early-stage integration of detailed climatic and solar analysis to maximize on-site renewable generation within a holistic design framework, is directly transferable. This approach offers a scalable model for sustainable hospitality and building projects in other high-irradiance, arid regions facing similar challenges of energy security and carbon mitigation.

The primary contribution of this analysis is its movement beyond a theoretical advocacy for renewable energy. It provides quantifiable, context-specific evidence that operationalizes the integrated framework, demonstrating how the Technical and Infrastructural Pillar directly enables the targets of the Environmental Pillar. By translating the design principle of "solar energy utilization" into the measurable outcome of 91.6% renewable energy sufficiency, the study effectively bridges the persistent gap between sustainable design aspiration and proven, economically-grounded performance. This offers a replicable blueprint for achieving high energy autonomy, thereby substantiating the practical viability of the proposed multi-pillar framework for sustainable development in similar climatic and socio-economic contexts.

Regarding real-world implications, the findings offer actionable pathways for multiple stakeholder groups. For policymakers, the 80.3% embodied carbon reduction demonstrates that mandating local material procurement and incentivizing passive design can yield decarbonization outcomes comparable to operational efficiency mandates. For developers and practitioners, the 14.68% site energy reduction and 91.6% PV self-sufficiency provide a financially viable investment case with a 13.4-year payback, lowering perceived risk in emerging markets. For the local community, the framework's integration of culturally resonant features (privacy, prayer spaces, and community halls) ensures social acceptance, which is a critical determinant of long-term operational success. Scalability to other cold semi-arid regions, such as parts of Iran, Tajikistan, and northern Pakistan, is supported by the transferability of the methodological sequence: climatic analysis, vernacular adaptation, parametric envelope optimization, and renewable energy sizing. However, site-specific calibration of material databases, labor skills, and grid reliability remains essential for replication.

3.3.4. Comparison with similar studies

The findings of this study align with and extend existing literature on sustainable hotel design in arid climates. Comparable to Haggag [69], who demonstrated a 20% cooling energy reduction in UAE hotels through passive design, the present study achieves a 20.66% cooling reduction while additionally integrating embodied carbon

optimization, a dimension often omitted in regional studies. Unlike Spanodimitriou [70], which focused solely on envelope retrofits in Gulf hotels, this work embeds passive strategies within a culturally responsive framework (privacy, courtyards, and prayer spaces), addressing socio-technical dimensions overlooked in purely technical assessments.

In the South Asian context, Vakil et al. [71] reported 12–15% energy savings in Indian hotels via PV integration and envelope upgrades. The present study exceeds this range (14.68% site energy reduction) while adding lifecycle carbon accounting (73.3% total reduction), demonstrating that vernacular material selection offers decarbonization gains comparable to operational efficiency measures. Compared to international benchmarks such as the proximity hotel [51], which achieved LEED Platinum through high-cost technologies, this study provides a low-tech, locally materialized alternative suited to resource-constrained settings, thereby expanding the applicability of NZEB principles to under-researched regions.

4. Conclusion

This study aimed to develop and evaluate a climate-responsive, culturally integrated Sustainable Hotel Model (SHM) for Ghazni, Afghanistan, addressing a critical gap in simulation-validated, context-specific hospitality design for cold semi-arid regions.

The research achieved its objectives through a mixed-methods approach. A household survey (N = 250) confirmed strong public endorsement for sustainability (76% priority) and solar energy (94.95% support), while revealing a lack of existing energy efficiency measures (77.78% perceived none). Expert interviews with 24 professionals informed a four-pillar framework comprising 65 design principles across the Socio-Cultural, Economic, Environmental, and Technical domains. Building performance simulation (Revit/EnergyPlus) quantified the proposed SHM's performance against a conventional baseline.

Key findings demonstrate that the integrated design achieves a 14.68% reduction in total site energy consumption, a 20.66% reduction in cooling demand, and meets 91.6% of annual electricity demand via on-site solar PV. Lifecycle carbon assessment shows a 73.3% total carbon reduction, driven primarily by an 80.3% reduction in embodied carbon through local, low-embodied-energy materials.

The study acknowledges limitations, including reliance on predictive simulation rather than empirical validation, and the need for pilot project implementation and post-occupancy evaluation. Future research should focus on developing localized life-cycle cost databases, investigating regulatory barriers, and conducting social impact assessments.

Ultimately, this research provides a replicable, simulation-evaluated blueprint for sustainable hospitality in arid, culturally significant regions. Its novelty lies in operationalizing vernacular wisdom and Islamic architectural values within a contemporary net-zero energy building framework, a synthesis previously absent in the literature for AFG.

This study addressed a critical research gap: the absence of a simulation-validated,

context-specific sustainable hotel model tailored to Afghanistan's cold semi-arid climate and Islamic cultural heritage. The primary objectives were to (1) analyze local climatic and cultural conditions, (2) develop an integrated hotel prototype combining vernacular passive strategies with active renewable systems, (3) quantify its energy and carbon performance through simulation, and (4) formulate actionable recommendations for implementation.

In response to the first objective, household surveys (N = 250) confirmed strong public endorsement for sustainability (76% priority) and solar energy (94.95% support), while revealing that 77.78% of respondents perceived no existing energy efficiency measures in local hotels. For the second objective, expert interviews with 24 professionals informed a four-pillar framework comprising 65 design principles across the Socio-Cultural, Economic, Environmental, and Technical domains, synthesized into the proposed SHM. Addressing the third objective, building performance simulation (Revit/EnergyPlus) quantified that the SHM achieves a 14.68% reduction in total site energy consumption, a 20.66% reduction in cooling demand, and meets 91.6% of annual electricity demand via on-site solar PV. Lifecycle carbon assessment demonstrates a 73.3% total carbon reduction, driven primarily by an 80.3% reduction in embodied carbon through local, low-embodied-energy materials.

The study acknowledges reliance on predictive simulation rather than empirical validation from constructed prototypes. Material databases may not fully capture local supply chain variations in Afghanistan, and occupancy schedules assume idealized patterns that may differ from real-world operations.

For the fourth objective, actionable recommendations include: (1) conducting post-occupancy evaluations of pilot projects to validate simulation assumptions; (2) developing localized life-cycle cost databases for Afghan construction materials; (3) investigating regulatory barriers to sustainable construction in provincial municipalities; and (4) performing social impact assessments to ensure community acceptance.

This research provides a replicable, simulation-evaluated blueprint for sustainable hospitality in arid, culturally significant regions. Its novelty lies in operationalizing vernacular wisdom and Islamic architectural values within a contemporary net-zero energy building framework, a synthesis previously absent in the literature for AFG.

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