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Strategies for Achieving Sustainability in the Architectural Design of Cold and Highland Regions

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Abstract


Sustainability in architecture, aimed at minimizing environmental impacts, has long been recognized as a significant and influential approach in contemporary design. This approach emphasizes the harmony between buildings and their surrounding environment and contributes to the formation of responsible architecture that is compatible with nature. Within this framework, architects, through understanding the climatic characteristics, site conditions, and cultural context of each region, are able to create spaces that not only respond to environmental requirements but are also aesthetically and culturally valuable, integrating seamlessly into the social fabric. This convergence of sustainability and contextualism in architecture has led to a new perspective in which buildings are no longer merely functional elements, but active components of a dynamic and living ecosystem. Sustainable architecture, through innovative design, efficient energy use, and the application of renewable materials, seeks to create structures that are both environmentally efficient and capable of enhancing the quality of life for users. The research methodology of this study is qualitative and case-based, and data collection is conducted through library-based research. Accordingly, recent national and international scholarly sources related to sustainability in architecture, particularly in cold and mountainous regions, were collected, translated, and analyzed. In this article titled “strategies for achieving sustainability in the architectural design of cold and highland regions”, fundamental concepts of sustainability in architecture are first introduced, followed by an examination of its importance in the design of cold and mountainous regions. Ultimately, the study seeks to answer the question of how sustainable architectural design can be achieved in these climatic zones.

Keywords: Sustainability, Design, Architecture, Cold and mountainous regions.

1 | Introduction

Humanity’s need for resources and energy has always been one of the fundamental and important issues in human life. With the ever-increasing demand for energy and the limited nature of fossil energy resources such as oil and gas, along with the environmental pollution resulting from their combustion, a new chapter of

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research has begun to harness natural resources such as wind and solar energy, opening a new window for humankind. Wind energy, which covers a vast part of this expansive land, as well as solar energy, are among the clean energy sources that have no limitations in their use.

The energy crisis in today's world is a very important and vital issue. The shortage of fossil fuels and non-renewable energy resources, on the one hand, and the pollution they create on the other, have made the use of clean and renewable energy a priority, especially in the field of architecture and construction [1].

Addressing sustainability requires a deeper understanding of its goals and recommendations in architectural design approaches. On the other hand, solving environmental, cultural-social, and economic problems, and the strong interconnection among these issues, directs us toward vernacular architecture and sustainable approaches, comparing and evaluating them in order to extract lessons for today's architectural design.

Vernacular and traditional architecture, as a concept in aesthetics and mysticism, is highly important in terms of purity of thought and respect for nature. Although vernacular architecture has undergone various transformations throughout history, it has managed to preserve its unique identity and reflects the customs, emotions, thoughts, beliefs, tastes, and artistic expressions of its people.

A study of vernacular buildings in any climate clearly shows that all such buildings are designed and constructed entirely based on climatic principles and with maximum use of natural energies, as well as protection against disturbing cold and heat. This approach is fully aligned with the culture of each region and is defined as vernacular and contextual architecture [2].

The aim of this research is to apply influential factors in the architectural design of cold and mountainous regions. By utilizing the concept of sustainability in design, construction in cold and mountainous climates can be aligned with environmental conditions. It seems that through intelligent architectural design, achieving this goal will become possible in the near future.

2 | Research Methodology

The research method is analytical and descriptive, carried out through library and internet-based studies. In this study, by reviewing credible scientific sources, the required data were collected. Accordingly, the research process was based on a content analysis of the scientific literature on the subject.

In a step-by-step process, first, a systematic search was conducted in reputable databases to review the relevant literature, and the identified documents were screened. Then, the selected reliable sources were subjected to content analysis in order to identify key themes related to the impact of sustainability on the architectural design of cold and mountainous regions.

In the next stage, the results of the previous step were examined using a descriptive-analytical approach, and based on the interpretation of the findings, recommendations were presented.

3 | Literature Review

Hazar Khani [3], in a study titled "sustainable design in cold and mountainous climates of Iran: a review of traditional architecture and modern technologies," found that combining traditional architecture with modern technologies can lead to more sustainable and low-energy designs. Such approaches are not only compatible with Iran's cold and dry climates but also align with the goals of sustainable development. This research offers innovative and practical solutions, particularly for architects and urban designers seeking to develop optimized and energy-efficient buildings in cold regions.

Nejad Ebrahimi et al. [4], in a study titled "the impact of climate on vernacular and sustainable architecture in cold and mountainous regions of Iran (Case study: Tabriz Bazaar)," emphasized that sustainable development has been a key topic in scientific discussions across various fields, especially architecture, for several decades. This issue is rooted in environmental problems such as increased consumption of fossil and non-renewable energy, rising greenhouse gas emissions, depletion of the ozone layer, global warming,

pollution, and ecosystem destruction, all of which contribute to biodiversity loss and depletion of natural resources. Therefore, the importance of climate-responsive design and its relationship with sustainability in architecture has become increasingly significant.

In cold and mountainous climates, fossil fuel consumption for heating buildings is very high due to low temperatures; thus, climate-responsive design in these regions is highly important. Paying attention to the physical design principles of buildings, especially bazaars, which hold significant architectural and urban value, is essential for developing climate-appropriate and sustainable design solutions.

Attia [1], in a study titled “sustainable architecture with a development-oriented approach,” found that sustainable development in architecture and urban planning can contribute to economic growth in the architectural and urban sectors. In the sense of progress, it leads to continuous advancement in scientific and cultural fields, and in terms of expansion, it supports the physical development of cities. The overall goal of human settlement development programs is to improve the social and economic conditions and the quality of life of residents. Achieving these improvements depends on technical cooperation and the participation of local communities in decision-making processes at various levels of development planning.

Zohuri Ghara Darvishloo [5], in a study titled “climate-responsive architecture in very cold mountainous regions: a case study of historical houses in Ardabil,” noted that relatively few studies have been conducted on cold and very cold mountainous climates and the vernacular architecture of such regions. Considering the noticeable lack of climate-responsive design in contemporary Iranian architecture, future research is expected to better understand vernacular climate-adaptive architecture and provide solutions for applying traditional architectural knowledge in modern design.

3.1 | Sustainability

The verb “Sustain” originates from the Latin word *sustinere*, composed of two parts: *Sus*, meaning “from below upward,” and *tinere*, meaning “to hold” or “to maintain.” It has been used in the English language since around 1290 AD. This verb is associated with concepts such as support, maintenance, and continuity. The adjective *sustainable* is used to describe a condition, state, or thing that is supported or maintained through assistance or the provision of means of subsistence and therefore continues to exist over time.

In Dehkhoda’s Persian dictionary, sustainability is defined as being durable and lasting. In Sokhan and Mo’in Persian dictionaries, it is similarly defined as stability and resistance, derived from the verb meaning “to persist” or “to show endurance.” For the adjective form, meanings such as stable, permanent, and resistant are also given.

The term sustainability, as used in this discussion, refers to something that can continue. In the definition of sustainable development provided at the 1987 Brundtland Commission (United Nations) [6], it is described as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable design is therefore an intervention in the environment that seeks to create solutions aligned with environmental, social, and economic goals in an integrated and holistic manner, achieving a balance that can improve the quality of life for the present generation while preserving resources for the future.

Based on these definitions, sustainable architecture can be briefly described as architecture that is responsive to its environmental and site-specific conditions and is based on the ecological capacities of its context, meaning it causes minimal environmental damage. In addition, it is adaptable to changing conditions and needs, ensuring continuity over time. Due to its site-specific characteristics, it is also distinctive and context-sensitive, providing an appropriate foundation for future generations.

3.2 | Architects' Views on Sustainability

Norman Foster: Sustainable design means the optimal use of architectural tools to save energy, instead of relying on unnecessary mechanical systems that contribute to global warming.

Jan Kaplický: The most important aspect of sustainable design is the selection of materials and the functional performance of a building under construction. Buildings should be self-sufficient in providing at least 80% or more of their required energy.

Richard Rogers: Sustainable design is a type of design that seeks to meet today's needs without harming the resources of future generations. Key principles include low energy consumption, high flexibility, and efficient use of resources.

Thomas Herzog: Sustainability can be considered one of the most critical aspects of our profession, as approximately 50% of energy in Europe is consumed in the building sector. In this regard, the role of architecture is extremely significant.

Ken Yeang: Sustainable design can be defined as a form of design that, throughout its life cycle, is fully in harmony with the Earth's ecological systems.

3.3 | Climatic Design Considering Sustainability Principles

Climatic design refers to a design that, while harmonizing with its surrounding natural environment and making maximum use of locally available natural energy, creates a suitable environmental condition for users as much as possible.

The term "implementation of climatic design" refers to specific construction methods aimed at reducing heating and cooling costs by utilizing natural energy flows to provide thermal comfort in buildings. To achieve this goal, two main actions are required:

- I. Studying the local climatic conditions in terms of human comfort.
- II. Designing the physical form of the building (which includes aspects such as building dimensions, area, type of walls, window sizes, and so on) [7].

Climatic design is a method for comprehensive reduction of a building's energy consumption and serves as the first line of defense against external climatic factors. In all climates, buildings designed based on climatic principles minimize the need for mechanical heating and cooling systems and instead make use of natural energy.

The main strategies for achieving climatic design goals include:

- I. Reducing heat loss in buildings.
- II. Reducing the impact of wind on heat loss.
- III. Utilizing solar energy for heating buildings.
- IV. Protecting buildings against intense solar radiation during hot periods.

3.4 | Climate-Responsive Architecture

Climate-responsive architecture is a type of adaptive design that focuses on the planning and organization of outdoor spaces. It incorporates ecology, sound social and economic policies, and climatic considerations.

The design of green roofs or rooftop gardens can also contribute to climate-responsive architectural projects. Rooftops can play a role in managing surface water runoff, supporting wildlife habitats, and enhancing environmental regeneration.

Climate adaptation appears to be a relatively new addition to the traditional Vitruvian principles of design—*firmitas* (durability), *utilitas* (functionality), and *venustas* (beauty). However, it can be integrated into both durability and aesthetics.

Creating green outdoor spaces is time-consuming but offers greater long-term benefits to users when less energy is consumed for maintenance, such as water, fertilizer, and other resources. Moreover, such systems can help reduce noise pollution, surface water runoff, and environmental contamination.

3.5 | Elements of Climate-Responsive Architecture in Cold and Mountainous Regions

The mountain ranges along the northern and western borders of the country have a cold climate. Cold and harsh winters and mild summers are among the main climatic characteristics of these regions. Low humidity in cold areas causes a large temperature difference between day and night. Extremely cold winter conditions are the main factor shaping the urban and rural fabric of the region.

The general climatic conditions of these areas are as follows:

- I. Severe cold in winter and mild conditions in summer.
- II. Heavy snowfall in the northern and northwestern regions of the country.
- III. Low air humidity.
- IV. Large temperature differences between day and night.

3.6 | General Characteristics of Urban and Rural Fabric in Cold Regions

- I. Small, enclosed urban and rural spaces.
- II. Dense urban and rural fabric with attached buildings.
- III. Sun orientation and topography are determining factors in the placement and expansion of settlements.
- IV. Main streets and pathways are aligned with terrain contours and are often narrow.

In this climate, urban and rural structures are compact and dense, and the external surface area of buildings is minimized relative to their volume to reduce heat exchange between indoor and outdoor environments. To prevent cold penetration and reduce heat loss, natural ventilation in winter should be minimized in these regions.

3.7 | Alleys and Passages in Cold Regions

In some cases, streets and passages are winding and covered. These covered passages are called *dalan* (corridors). The roofs of these corridors are constructed using arches and vaults to minimize the penetration of cold air into the streets and houses.

North–south oriented streets are designed so that snow and ice accumulated in the passages can melt under sunlight. In east–west oriented passages, due to continuous shading during the day, snow and ice may remain in the streets for extended periods throughout the cold season.

3.8 | General Characteristics of Building Form in Cold Regions

- I. Compact and dense floor plans.
- II. Buildings with central courtyards and inward-oriented layouts.
- III. Low ratio of external surface area to building volume.
- IV. Low ceiling heights.
- V. Flat roofs, often used to retain snow as thermal insulation.

VI. Small openings.

VII. Small verandas (iwans) and courtyards.

VIII. Relatively thick walls.

3.9 | Roof Coverings in Cold Regions

Buildings in Iran's cold climate are mostly flat and beam-supported. However, sloped roofs can also be seen in the foothill areas of the northern Alborz mountain range. In regions where flat roofs are used, parapets are often omitted to facilitate snow removal and to increase solar radiation gain.

If the goal is to use snow as thermal insulation, flat roofs can be an appropriate solution. On the other hand, when sloped roofs are selected, the still air layer between the outer roof surface and the inner ceiling (false ceiling) can act as thermal insulation.

3.10 | Openings and Windows in Cold Regions

The size of openings in cold climates is generally smaller to minimize heat exchange between indoor and outdoor environments. However, openings facing outdoor streets are relatively larger compared to those in hot and dry climates.

By designing larger openings on the southern façade, a significant amount of solar heat can be utilized during winter. In contrast, openings exposed to cold winter winds are minimized as much as possible, and in some cases, they are eliminated on windward façades.

3.11 | General Characteristics of Building Materials in Cold Regions

I. Use of heavy materials with high thermal capacity.

II. Use of stone (rubble or cut stone) in foundations and lower floors.

III. Use of Adobe and brick in upper floors.

It is recommended to use clay and mud-based materials in walls due to their high thermal capacity. The use of rubble stone at the base of adobe walls (plinth/base of walls) is an effective solution to prevent rising damp in buildings.

In cold climates, materials with high density and thermal capacity are preferable. Building surfaces and façades are often finished with dark-colored materials and rough textures so that solar heat during winter is better absorbed into the walls [8].

4 | Discussion and Conclusion

Sustainability in architecture is a concept or phenomenon that is currently being addressed in most countries around the world by many architects with different tastes and perspectives. Although sustainable architecture is a global concept, it is also inherently local. In other words, while it shares universal principles, it acquires specific and distinct meanings in each socio-cultural context.

From this perspective, sustainability addresses not only global problems such as pollution and climate change, but also local environmental issues such as water and soil conservation and the revitalization of small towns. It offers solutions based on both advanced technologies and simple indigenous technologies, which are often integrated within a single project. This approach combines space as an architectural expression with the concept of sustainability, transforming it in the process.

From a climatic perspective, the foundation of spatial design is human thermal comfort and the creation of suitable environmental conditions for better living. In other words, climatic studies in this context aim to create spaces that achieve suitable environmental conditions with minimal use of fossil energy.

In the past, the organization of building layouts and interior spaces was based on climatic conditions. However, today, due to the standardization of materials, imitation of Western architecture, the marginalization of local materials, cost-effectiveness, easier access to modern materials, and the aesthetic appeal of contemporary construction, buildings are often designed without considering climatic conditions.

The influence of climate on architecture is undeniable, and design without regard to climate is both flawed and costly, and does not provide desirable conditions in terms of quality of life and thermal comfort. Therefore, attention to climatic factors in design improves environmental conditions, makes buildings healthier and safer, reduces energy consumption, and consequently minimizes environmental damage. This interdependence highlights the reciprocal relationship between humans, climate, and architecture.

Overall, the aim of this research is to provide strategies for creating comfort and utilizing natural climatic factors in architectural design in order to reduce energy consumption, adapt buildings to local climate conditions, and minimize environmental impact.

Cold and mountainous regions experience cold and humid winters and semi-dry summers, with long winters and short spring and autumn seasons. The warmest months are July and August. The main challenge in such regions is the dominance of cold conditions for more than six months of the year.

During the months of November, December, January, February, March, and April, due to temperatures falling below comfort levels, mechanical heating systems are required. However, during the remaining months, mechanical systems are generally unnecessary, and natural elements such as wind and solar radiation can be utilized to achieve comfort. In spring and summer, the climate is generally mild and does not require mechanical systems.

Thus, it can be said that comfort conditions are naturally achieved in approximately 50% of the year. In the remaining periods, heating systems are necessary due to prevailing cold conditions. However, in November and April, most days do not require mechanical heating, except at night. Therefore, architects should consider solar angles in winter and prevailing wind directions when planning buildings.

Design should allow maximum use of solar radiation during cold seasons, while shading systems should prevent direct sunlight penetration from early May to late August. Additionally, openings should be oriented to utilize wind flow for natural cooling during warm periods.

If sustainable design principles are properly applied in these regions, there would be no need for cooling systems throughout the year, and natural ventilation could ensure comfort in warm seasons, eliminating cooling energy costs. For winter comfort, although sustainability can significantly reduce heating demands, mechanical heating systems remain necessary.

Given the climatic conditions of cold and mountainous regions, which include cold winters and autumns, and warm, dry summers, the following recommendations are proposed:

- I. Designing compact and dense building plans.
- II. Orienting buildings toward the south with an east–west plan layout.
- III. Using heavy materials with appropriate thermal lag.
- IV. Placing windows on the southern façade to maximize daylight use.
- V. Using double-glazed and insulated openings to minimize heat loss.
- VI. Maximizing solar gain in winter for passive heating.
- VII. Preventing infiltration of cold winter winds through proper window placement and sealing.
- VIII. Reducing the ratio of external surface area to building volume and limiting ceiling height.

5 | Conceptual Framework

This model is a conceptual framework that illustrates the relationship between cold and mountainous climates and the resulting performance outcomes of sustainable architecture. In essence, the diagram represents a cause-and-effect chain that begins with natural conditions and leads to environmental, economic, and comfort-related outcomes.

Below is a full explanation of each section:

5.1 | Climatic Conditions (Cold and Mountainous Regions)

This section forms the foundation and starting point of the model. All design decisions must be based on climatic characteristics.

Main features of this climate:

- I. Low temperatures during winter.
- II. Heavy snowfall and strong winds.
- III. Low air humidity.
- IV. Large day–night temperature differences.
- V. Long heating seasons with short, mild summers.

These conditions create a strong need for buildings to retain heat and minimize energy loss.

5.2 | Natural Energy Resources

At this stage, the model emphasizes that instead of relying on fossil fuels, natural energy sources should be used:

- I. Solar radiation for heating and daylighting.
- II. Wind flow for natural ventilation or temperature regulation.
- III. Passive environmental forces, such as temperature differences and thermal mass effects.
- IV. These resources form the basis of climatic and sustainable design and replace energy-intensive mechanical systems.

5.3 | Vernacular Architectural Principles

This section shows that traditional architecture in cold regions is the result of long-term human experience with climate and is naturally adapted to environmental conditions:

- I. Compact building form to reduce heat loss.
- II. Thick walls (thermal mass) for heat storage.
- III. Controlled openings to reduce cold air infiltration.
- IV. Central courtyards to create thermal balance and protect interior spaces.
- V. Climatic roof systems for snow management and thermal insulation.

This section essentially represents “local/indigenous knowledge.”

5.4 | Sustainable Design Strategies

At this stage, vernacular principles are combined with modern architectural knowledge and transformed into design strategies:

- I. Proper building orientation toward the south to maximize solar gain.

- II. Reducing the surface-to-volume ratio to minimize heat exchange.
- III. Use of materials with high thermal mass.
- IV. Controlled natural ventilation.
- V. Solar gain control.
- VI. Protection against cold winds.

This stage translates traditional experience into scientific and practical design methods.

5.5 | Performance Outcomes

The final section of the model presents the results and impacts of this design approach:

- I. Reduced energy consumption (heating & cooling).
- II. Improved thermal comfort for occupants.
- III. Lower operational costs of buildings.
- IV. Environmental protection.
- V. Improved quality of life and settlement sustainability.

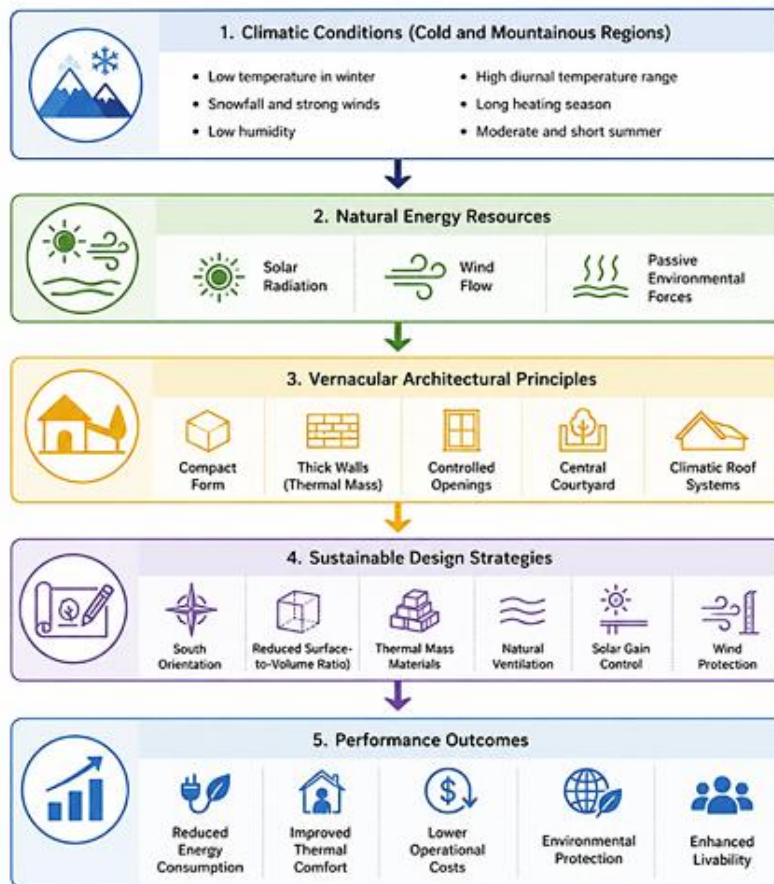


Fig. 1. Conceptual flowchart illustrating the relationship between climatic conditions, vernacular architectural principles, sustainable design strategies, and performance outcomes in cold and mountainous regions.

5.6 | Overall Summary of the Model

The diagram shows that:

Climate → Natural resources → Vernacular architecture → Sustainable design → Performance outcomes

In simpler terms, the model explains that if architectural design is based on climate, informed by vernacular architecture, and integrated with sustainability principles, the result will be low-energy, environmentally compatible buildings with high levels of comfort.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

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Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

Conflict of Interest

The author declares that they do not have any conflict of interest.

Consent for Publication

The author confirms consent for the publication of this work

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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