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Article

Vernacular Iranian housing as a sustainable model of functional and aesthetic comfort in contemporary passive dwellings

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Abstract: In the recent years, with global warming and the change in climatic characteristics, buildings and interior arrangements in dry and cold climates, that previously did not have cooling problems, now require built and pre-planned cooling systems as well as heating. On the other hand, the enormous increase in energy consumption and the rapid depletion of energy resources causes concern and anxiety for future generations. In this regard, utilizing natural resources and incorporating sustainable solutions into building design are critical. Vernacular technical systems and design ideas can still be accepted and applied to create sustainable solutions. In this context, design strategies for energy efficiency and provision of physical and spatial comforts could be considered based on traditional architecture. In this study, sustainable building design solutions that have been used in Iran's vernacular houses, which has four distinct climate zones, aimed to create a paradigm for the general modern passive house designs in the global context. Traditional Iranian residential architecture incorporates architectural features for physical, spatial, and climatic needs, as well as aesthetic comfort for the user. In this manner, user needs and interior space organization in vernacular residential architecture can be considered as a sustainable housing model that meets today's technology requirements in passive house design.

Keywords: vernacular architecture; sustainable architecture; passive house; functional needs; aesthetic comfort

1. Introduction

With the world's growing population and decreasing natural resources, sustainable design has emerged as the primary focus of architecture and urban planning. However, traditional architecture in any region has evolved over time in response to changing environmental conditions. Vernacular architecture has addressed the physical comfort and aesthetic needs of users by responding to various climatic, geographical, social, and cultural issues.

Many countries, like Iran, have used sustainable design principles in their traditional and vernacular architecture. Physical, economic, social, and cultural values of Iranian vernacular architecture reflect environmental factors. These features, integrated with user comfort, have maintained their continuity over the years in different climates. The spatial organization, formal and functional characteristics of traditional houses and their design with climate-sensitive strategies can be a guide in today's architectural and urban planning design.

Passive methods to provide a comfortable and energy-efficient indoor environment in various climates have been widely investigated. Modern houses and constructions are high-energy consumer and unsuitable for the climatic, cultural, and social contexts of the region. For this reason, the buildings must be designed according to the winter and summer requirements. In Iran’s vernacular housing, the users’ comfort was maintained by a combination of several passive strategies of thermal control, resulting from a comprehensive knowledge of climatic conditions. Iran’s traditional architecture is particularly focused on providing comfort in different seasons, resulting in vernacular housing that integrates climatic data and local resources.

As a result, this study will examine numerous environmentally friendly techniques used in Iranian vernacular buildings, which can serve as a model for the functional and aesthetic comfort of modern passive housing. The findings of the study, which will be evaluated through a comparative analysis of existing traditional houses, are as follows:

1) The physical and spatial components of Iranian traditional architecture consider both aesthetic comfort and the user’s functional needs;
2) The aesthetic and functional integration in vernacular architecture can be a model for creating sustainable interiors;
3) The traditional architectural strategies, combined with today’s technology, can influence the re-creation of contemporary sustainable interiors as well as the renovation of existing buildings.

2. Materials and methods

The methodology of this study was determined by climatic design and analysis of the Iranian buildings. The focus of the research framework is to harmonize buildings with the natural and environmental conditions and resources and focus on user’s need and comfort based on the sustainable vernacular Iran houses.

The research design was shape by a comprehensive analysis on Iran vernacular architecture and sustainable housing methods and principles. The various environmentally and climatic characteristics of Iran and their reflection on vernacular houses have been systematically analyzed step by step from the building-urban relation to the form and architectural elements of houses. As a result, this study attempted to provide scientific contribution by evaluating the sustainable and climatic design principles of vernacular Iranian houses with a holistic approach to combine with contemporary buildings. In this context, in order to develop a model for contemporary passive dwellings, the functional and aesthetic comfort strategies of traditional sustainable houses will be determined according to different climatic characteristics.

Based on the classifications in the literature studied, the results of inquiry involved in this study will be evaluated regard to two folds as below:

- Functional Comfort: Physical sustainable features of various climatic regions of Iran traditional architecture gathered and systematize through various data;
- Aesthetic Comfort – Research on sustainable aesthetics based on various aspects of Iranian social and cultural features will be associated with traditional comfort characteristics.

The research findings were combined, and a design framework was developed to collect functional and aesthetic data on traditional approaches as a whole. This framework aims to compare and adapt conventional sustainable strategies to the requirements and methods of modern passive dwellings benefiting from advanced technologies. This strategy, while establishing a role model for today's passive dwellings, seeks to encourage climatic design and environmentally and ecologically friendly design decisions through the proper use of natural resources. In this regard, the adaptation of local climatic techniques in modern dwellings will influence strategies for both renovating existing buildings and rebuilding new ones.

The environmental sustainability of vernacular architecture and interaction with nature, history and cultural identity can offer a design that can satisfy today's needs while benefiting from advanced technologies (Arbabzadeh et al., 2020).

3. Iran vernacular housing and sustainable architecture

Climate and environmental characteristics are one of the main factors influencing the traditional architecture and the shaping of local houses. Wind and sun direction, humidity, air pressure, temperature, and rainfall are climatic elements that influence building's orientation, location and formation.

The environmental, climatic, social and cultural characteristics of Iran's traditional architecture embody the principles of today's sustainable approach. The following principles are examples of sustainable architecture in today's discussions:

1) Being affected by cultural, environmental, and climatic factors;
2) Compatibility with nature and the environment;
3) Energy efficiency;
4) Effective response to functional requirements;
5) Effective use of suitable (local and climatic) materials, both visually and environmentally;
6) Influenced by vernacular architecture in a modern approach.

Even though Iran is generally classified as a dry country is actually a multi-climate region. In fact, it is climatically diverse and can be divided into four main climatic regions. In four separate regions of Iran, climatic characteristics influence the design of urban fabric, building forms and position, spatial organization, material and natural energy consumption. This has secured the sustainability of Iranian vernacular architecture (Ghobadian, 1998). Despite the lack of technological possibilities in traditional Iranian architecture, unlike today's buildings, it has maintained user comfort with the correct use of natural resources, instead of struggling with natural conditions.

Iran's vernacular housing architecture is sensitive to climate requirements and has sustainability features based on functional, environmental, social, cultural, and economic factors, such as passive heating and cooling from renewable solar and wind energies, harmony of form and function, natural cooling and ventilation features, the use of recyclable natural and domestic materials, and the use of high thermal capacity mass and energy-efficient thick insulation walls.

Iran's traditional architecture is based on climate and sustainability status of four climates: hot and humid, hot and dry, temperate, and humid and cold. In this regard, urban fabric and building forms have been considered to utilize natural energy resources such as sunlight, wind, geothermal and hydro energy. Furthermore, the materials chosen are climate-appropriate, locally available and economical. Climatic, environmental and even social and cultural elements influence the topology of houses or buildings in various parts of Iran. In this regard, vernacular housing's climatic design in various regions of Iran could be summarized as follow:

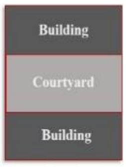
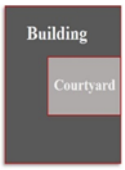
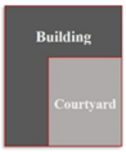
Hot and dry climate: This region experiences hot-dry summers and cold-dry winters. The temperature difference between day and night is large due to low humidity. In this case, traditional architecture's sustainable solutions ensure user comfort by balancing buildings and environmental conditions. Overall, the architecture and form of the houses in this region can be summarized in the following **Table 1**.

Hot and humid climate: The hottest region of Iran in the southern coastal zone which is mild in the winter and hot and humid during its long summer months. In this region, providing shade and cross ventilation is the most effective natural technique to create comfortable conditions which can be achieved by wide balconies, large opening facing the sea, and wind towers (Ghobadian, 2021) (**Table 1**)

As a result, prevailing winds as natural ventilation and shading for sunlight are the two most important elements influencing the orientation and structure of the urban fabric in hot-dry and hot-humid climates (Ghobadian, 2021).

Cold climate: This region is cold and snowy in the winter and hot and dry in the summer. Therefore, the traditional urban fabric was compact with buildings connected to one another to provide protection to protect against cold weather and winter wind. The features of traditional houses in cold region had the following characteristics (**Table 1**).

Table 1. Sustainable features of vernacular houses in various regions of Iran.

Architecture and form of vernacular houses	Inside-outside relationship	Building form	Courtyard	Roof/Ceiling	Walls	Material	Sustainable architectural elements	Plan form
Hot and dry climate	Ground floor lower than street level	Adjoined and inward oriented	central courtyard	Domes or convex roofs/High ceilings	Thick walls	Clay (mud, adobe, and brick)	basements, verandas and often wind towers	
Hot and humid climate	Ground floor above natural ground	Partly adjoined and partly inward oriented	Central courtyard with openings both around it	Flat roofs	High ceilings and windows, large opening facing sea	Walls stone, brick, adobe, or coral stones. Roofs timber and covered with palm	Big and spacious verandas and balconies, wind tower, mostly no basements	
Cold and dry climate	Ground floor lower than street level	Adjoined and inward oriented	Central courtyard	Flat roofs/Low ceilings	Thick masonry walls/small openings	brick or adobe for walls/Timber for roofs	Small or no verandas/Basement with short roof	

The formation of vernacular architecture reflects physical, social, economic, and cultural interactions with the natural environment. This approach considers community needs, natural factors, as well as the user's functional and aesthetic requirements (Oshrieh and Amiri, 2016).

Nowadays, as the seasons alter due to global warming, regions with cold climates experience hot and dry or hot and humid summers. Thus, it is necessary to integrate not only the characteristics of the winter months within the framework of sustainable housing design, but also the user needs of the extending summer season into the design. In this sense, the sustainable features of houses in cold regions can be examined for the winter season, while those in hot and dry climates can be evaluated for the summer season.

Traditional Iranian architecture's physical and spatial features address a variety of human practical needs as well as recreational and aesthetic purposes. Iran's traditional residential architecture, which is based on sustainable principles and climate-sensitive strategies, will be analyzed functionally and aesthetically.

3.1. Functional sustainability

Functional sustainability of Iran architecture consists of factors which work together rather than independently. The physical principles of Iranian traditional buildings were determined by considering environmental and climatic factors, as well as utilizing natural resources. According to the sustainable factors and strategies summarized in **Table 2**, the study's aim of determining the approach for today's passive dwellings will be met by combining climate parameters.

Table 2. Functional sustainable factors of vernacular houses of Iran**.**

Sustainable factors	Solar energy (thermal heating, day lighting, shading)	Wind (ventilation, thermal cooling)	Water/plants	Material (thermal comfort)	Architectural elements
Strategies of Iran vernacular houses	Natural lighting, the form and situation of building, openings, shading devices, Spatial organization	Opening (position, size), wind catcher, connective and evaporative cooling	Cooling, evaporation, humidify of space	Climate appropriate, local (available in the region), economic	Courtyard/Wind catcher/Iwan/water ponds/Hozkhaneh/Yakhchal

3.1.1. Solar energy

Energy efficiency and provision of visual comfort in vernacular buildings are based on using and controlling strategies of natural lighting. In this regard, Climatic design of sustainable architecture in various zones of Iran was constructed by minimize solar gain for hot and dry region and maximize for cold region. The form, size and orientation of building and openings play the main role to use solar energy efficiency. Shading devices such as revak (portico) tabeshband (vertical fins), sarsayeh (horizontal fins) and orosi (windows with colorful glasses) control the daylighting in hot regions (Maghsoudi et al., 2015). In cold climates, architectural light-receiving systems such as top and side lighting with varied openings are used. The forms and spatial organization of vernacular houses were created according to climatic characteristics to meet the needs for sun protection and sun absorption in different seasons.

3.1.2. Ventilation

Wind is an important climatic factor for the natural ventilation and provision of cooling in vernacular architecture of Iran. Natural ventilation is provided by openings for cooling the thermal mass of the building and supplying fresh air. The use of thermal mass, high cross flow ventilation, and night cooling is crucial for thermal comfort (Iravani et al., 2009).

Ventilation solutions for hot and dry regions include nocturnal cooling, evaporative cooling and convective cooling (cross-ventilation). These systems can be summarized as below (Khorsand Mashhadi, 2012):

- Nocturnal cooling: occurs when heat from the building is radiated to the sky at night, allowing the masonry surfaces and building mass to cool naturally.
- Evaporative cooling: the process of exchanging sensible heat in the air for the latent heat of water droplets on wet surfaces by installing water elements (pool and qanat) in vernacular buildings.
- Convective cooling (Wind catcher and openings): this method was developed in two ways during the nighttime. The first is the descent of cold air from the roof into the courtyard, while the second involves the utilization of wind towers and wall openings in hot, dry climates (**Figure 1**).

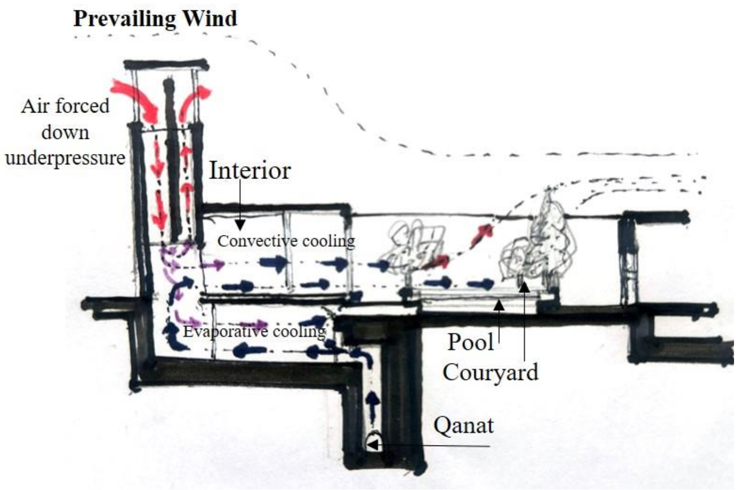


Figure 1. Convective and evaporative cooling by wind in wind catcher system.
Source: Author.

In hot-dry climates, prevailing winds captured by wind catcher or wall openings at the edges of the courtyard enter the interior spaces and remove heat from the building during the night (Khorsand Mashhadi, 2012).

Wind catcher: Badgir (wind catcher/wind tower) as one of the most original and traditional elements of vernacular architectures in hot-dry climates, used for natural ventilation. Wind catcher could capture the wind at the roof level of the building and direct it down to the rest of the interior depending on wind direction, velocity and temperature difference (Arbabzadeh et al., 2020). Wind catchers ventilate the rooms by simulating chimney effect and are designed and built in various shapes depending on their height and desirable wind direction.

Openings in the building envelope provide ventilation in the interior by establishing the connection between the outside and the inside. Therefore, the intensity, direction and other features of the prevailing wind are critical factors to be considered in the design of openings to ensure user comfort, especially in hot climates (Khorsand Mashhadi, 2012, Zandi, 2006). The position, size, and direction of the opening have a complete impact on its efficiency.

In hot and dry climate windows should be relatively small, especially on exterior walls and must be shielded from direct radiation and glare. Large windows should face north and south. In Courtyard houses openings were situated both around their central court yard and also on their external walls. This allows for cross-ventilation of the rooms. Wide balconies, large openings facing sea air, and wind towers provide additional shade and cross ventilation (Ghobadian, 2015).

Overall, in vernacular houses of Iran the use of thermal mass, high cross flow ventilation and night cooling is critical in achieving thermal comfort (Iravani et al., 2009).

3.1.3. Water

Sustainable systems such as water ponds, Hozkhaneh, Yakhchal, Ab-Anbar and Qanat built inside the vernacular dwellings and inner courtyards with proportions that allow for cooling played a crucial role in various climate zones. Evaporation cools and humidifies the air in hot and dry climates (Sahebzadeh et al., 2020). Wind towers were erected in the paths of ponds in vernacular architecture in order to utilize the wind effect to cool the house.

3.1.4. Combinational system of water and wind power

Hozkhaneh: A cool place to live in hot and dry regions, inside the buildings known as 'Hozkhaneh'. In this area, there is a pond full of water, and the wind from the wind catchers' holes is directed to this area via some channels, causing evaporation. In fact, the wind cools the atmosphere by evaporating water (Eirajia and Akbari, 2011).

Ab-anbar (Water Reservoir): Ab-Anbars is combination of wind-catcher functions and dome-roofs, designed to provide sustainable comfort for users. The Ab-Anbar, which is excavated to a depth of 10 to 20 meters on the ground, covered by a dome-shaped roof, and equipped with several ducts, is a pond or indoor pool that was traditionally built underground to store and cool water (Yousefi and Nocera, 2021).

3.1.5. Construction material

Climatic factors on building design have a significant impact on material selection. As a result, it is critical to choose materials that can adapt to a variety of climate conditions. The main features to be considered in the selection of the material are thermal capacity and thermal resistance according to the characteristics of the region where the material will be used. Furthermore, material availability and locality are significant aspects of sustainable design.

In hot regions, using materials with low thermal mass that do not store heat in themselves are suitable while in cold zones materials with high thermal mass are useful for absorbing heat from the sun during the day and maintaining heat at night (Ghobadian, 1998).

3.2. Aesthetic sustainability

The new buildings of contemporary architecture, which has been created without the slightest cultural and social harmony, whereas the traditional architecture was formed based on the geographical, environmental and climatic factors, and has its unique architecture. The similarity of new structures with varying environmental, functional, and physical aspects causes the change of socio-cultural values. These changes in people's culture and living structures; have occurred solely under the banner of modernism, with little concern for environment or its inhabitants (Oshrieh and Amiri, 2016). This type of structure has not only lost its identity and uniqueness by absorbing foreign and urban architecture, but it also conflicts with nature by requiring the use and consumption of fossil fuels for heating, cooling, ventilation and maintaining user comfort.

However, the most significant flaw of today's buildings is lack of attention to its cultural, place-based and aesthetics aspects. Sustainable aesthetics, as an important part of human-centered social and cultural sustainability, considers and respects the dynamics of human interventions with natural phenomena (Daugelaite and Grazuleviciute, 2020).

On the other hand, sustainable design should have both aesthetic and functional qualities. Culturally, environmentally, and socially design that harmonizes with the place and is not foreign or contradictory to the local identity has sustainable aesthetics. According to this description, designs that are human well-being, prioritize user comfort, aesthetic enhancements, and techniques that conserve cultural values can be sustainable and long-lasting (Berardi, 2013).

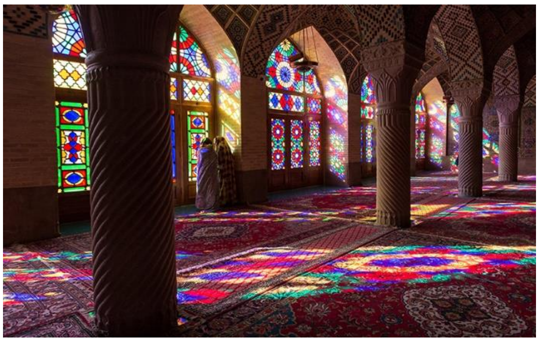
Space and time were harmonized in Iranian vernacular architecture, and functional requirements are combined with environmental, social, economic, and cultural factors, as well as aesthetic values to ensure sustainable integrity. In addition to the physical and functional aspects of traditional Iranian architecture, we can outline the following elements and factors that assure sustainability in terms of aesthetic comfort in vernacular housing:

3.2.1. Natural lighting

The use of natural lighting and shadow effect in traditional Iranian houses is critical not only functionally but also aesthetically. The utilization of symbolic characteristics of daylight in traditional Iranian houses, the decorating and design of facades, and the creation of virtual and dynamic textures on the monotonous surface of the building all demonstrate that light is a dynamic and aesthetic element in architecture.

Latticed windows with colorful glasses (Orosi): In the building located in a hot and dry climate of Iran, the design used as a shading element named 'Orosi' in the openings also meets the user's aesthetic comfort inspired by environmental and cultural values with its pattern and texture. Orosi is a traditional Iranian window made of colored glass put into a wooden latticed frame. This window was built for traditional courtyard houses in central Iran and functions as a passive approach for controlling light intensity while also providing privacy and aesthetic value (**Figure 2**).

(a)



(b)

Figure 2. Orosi as a functional and aesthetic element in iranian vernacular buildings. **(a)** Traditional Iranian window in hot and dry region (memarifa, 2024); **(b)** the interior atmosphere which is created with color and texture used in the windows (memarifa, 2024).

One of the most beautiful structures created considering the aesthetical aspect of light is Ororsis, which are latticed windows with colorful shards of glass that create a spiritual atmosphere by producing attractive light effects within buildings (Pirnia, 2006). Furthermore, it is a useful instrument to lessen the undesirable intensity of sunlight. Orosi window is not only a decorative element, but also functional, being double-layered, controlling infrared heat entering the building, keeping insects and living creatures away, affecting the acoustics of the space and creating a wide exterior view. They are made in various geometric designs, thin or a combination of both and in different sizes (Noori and Bashiri, 2014).

3.2.2. Ventilation and shading elements

Veranda (Iwan): Iwan is one of the significant sustainable elements in traditional houses of Iran. In architecture of hot regions of Iran Iwan as a semi open space provide coolness, shadow and ventilation however usually built as a transition/connecting space to get in or out of a space.

Investigation on the climatic role of Iwan in the houses of cold and snowy region shows that, in most of cases, is located along the main axis of the house to have the maximum advantage of southern sunlight. Iwan also protects the house from the rain and snow (Nejadriahi, 2016). Iwan also provides privacy as a cultural value while ensuring an inside-outside relationship. As a result, it serves as a connection between private and public areas. Furthermore, the form and design of the Iwan in Iranian architecture enhances the aesthetic value of vernacular houses. Therefore, the existence of Iwan at the initial layer of the building contributes to both aesthetic and climatic sustainability.

Water (hoz, hozkhane):

Water's aesthetic value in vernacular Iranian housing is just as important as functional features. A small pool in the courtyard to humidify the air and provide a better view, as well as a narrow water canal in the pool to spread the sound of the water stream in the space, causing the water to splash and make noise to create a sense of peace, are all examples of how water is used as an aesthetic element in Iranian vernacular architecture (Pirnia, 2004).

3.2.3. Material

In traditional houses of Iran, the preference of local, accessible, climatic and economic materials provides cultural and aesthetic values as well as functional sustainability. In this regard, the color, texture, and visual features of the materials are important aspects that symbolize various periods and zones of Iran. Thus, the material utilized in vernacular housing design provides the user's physical and aesthetic comfort in terms of environmental, social, cultural and economic aspects (**Figure 3**).

(a) **(b)**

Figure 3. Difference of material as a cultural identity and aesthetic feature in vernacular houses of various zones of Iran. **(a)** An example of vernacular house in the center and hot climate of Iran (İran'da gizemli "Kaşan Ahavan, 2024); **(b)** an example of vernacular house in the north and humid climate of Iran (Stir world, 2024).

3.2.4. Sight and view

The depth of the landscape and the use of the sight and landscape in relation to the appropriate activities of people in the landscape are considered as an aesthetic value of vernacular Iranian houses. In traditional Iranian houses, structural elements such as the entrance of the house, vestibule, entrance hall and courtyard provide exterior view and vista. The form and structure of these elements were influenced by different climates of regions.

The natural view and geometry of the houses, the color, texture, material and amount of glazing of the openings, the perception of depth between open and closed spaces provided by semi-open areas are the visual comfort and aesthetic aspects of vernacular architecture.

Aesthetic aspects of sustainability are just as important as functional and technological components of sustainable architecture which must be researched and incorporated in contemporary buildings. Overall, a sustainable design can be defined as a structure responds to functional and aesthetic needs simultaneously. To provide physical, visual, and aesthetic comfort, contemporary sustainable dwellings should be designed and built in a functionally efficient manner, incorporate ecological principles, social and cultural quality, integrate with the local environment, and contribute to aesthetics development (Berardi, 2015).

According to the findings of the study, Iranian architecture, which has different characteristics in each climate, has common solution languages functionally and aesthetically.

4. Results: Passive design with traditional architecture strategies

Sustainable principles strategies were effectively incorporated into the design of Iranian vernacular houses. According to the findings of the study, Iranian architecture, which has different characteristics in each climate, has common solution languages functionally and aesthetically.

The functional sustainability design of the traditional house based on solar and wind energies, was built significantly influenced the plan form, openings and spatial organization design of the house as well as the major design decisions emerging from cultural and aesthetic assessment. The spatial arrangement and diversity of vernacular houses changed according to the climatic and environmental needs.

The study, which focused on the use of functional and aesthetic sustainability methods in Iranian vernacular architecture, will evaluate these strategies in the context of construction and renovation of contemporary dwellings under the passive design strategies.

Housing is an essential human requirement; hence it should be created more sustainably. Passive houses can be considered as an environmental, economic, and political solution. The passive house concept reduces the use of external energy sources for thermal comfort, which has the potential to reduce the demand for heating and cooling through better building designs by integrating building technologies, energy systems, and user activities in their daily lives (Vrotsou and Glad, 2021).

Sustainable architecture is an approach to build or communicate a relationship between user's needs, comfort and activities with their natural and cultural environments. The interaction of daily activities with the heating, cooling, and ventilation systems is critical to enhancing our understanding of sustainable user comfort in passive dwellings. Passive house design considers the interior organization, main orientations, openings and window placements, heating, cooling, and ventilation systems to ensure that the building's design adapts to the user's daily practices and has a comfortable indoor climate through careful planning of the building orientation.

Table 3. Principles of sustainable design based on architectural quality and cultural pertinence.

Design	**Architectural Design**			**Design Process**	
Sustainable architecture principles	Integration	Equity	Precaution	Shared responsibility	Participation
Passive house concept	Integration of environmental, energetic, economic, social/cultural, aesthetic	Present and future equality (including spatial, social and environmental aspects)	Flexibility of the building design: taking precautions with actual needs + historical past + future possibility	Considering physical and psychological needs of the user together	Building design + construction + management = work together

In this context, as Van Moeseke stated, the compatibility passive houses approach with the concept of sustainable design can be analyzed using five basic principles defined by de Myttenaere. The first three principles (integration, equity and precaution) challenge architectural design, while the last two (shared responsibility and participation) challenge the design process (Van Moeseke, 2011). Passive house strategies help to improve users' comfort and well-being while reducing energy use and waste (Vrotsou and Glad, 2021). The fundamental principles of the passive house concept can be stated as utilizing natural resources and minimizing the use of fossil resources for building's heating and cooling, and complying with environmental impacts. In this context, the concept of passive house might be considered as compatible and parallel with the principles of sustainable design (**Table 3**).

The first strategy of passive house, focuses on heating the building and the heating features, such as thermal insulation, solar energy consumption, and heat recovery. The passive house concept also includes meeting the building's other energy needs through renewable and natural sources (Ionescu, 2017). Passive cooling refers to any design element or technology that reduces the temperature of a building without using electricity. In light of the above information, the characteristics of the passive house can be summarized as follows:

- Passive design solutions use renewable energy sources such as the solar and wind to improve interior's heating, cooling, ventilation, and lighting.
- It can also reduce environmental impact, including greenhouse gas emissions and energy use.
- Passive cooling improves indoor air quality by reducing temperature variations between interior and outdoor surroundings.

The environmental, energetic and economic similarities between the strategies in traditional Iranian houses and the modern passive house concept under the main heading of sustainability demonstrate that these two approaches can be evaluated according to the functional-aesthetic sustainability principles. As a result, the deficiencies and inadequacies of the modern passive house concept can be complemented with traditional methods. The interaction of sustainable principles (**Table 3**) with vernacular and passive houses can be summarized based on functional and aesthetic sustainability in **Table 4**.

Table 4. Principles of sustainable design in vernacular Iran houses and passive design strategies in contemporary dwelling**.**

Sustainable Architecture	**Functional Sustainability**					**Aesthetic Sustainability**
Vernacular House	Solar energy	Wind/Water/plants (natural (ventilation)	Thermal (cooling/heating), Integration of summer and winter comfort criterion	Material (thermal comfort)	Architectural elements	Cultural background+ physical-conceptual coherence
	Natural lighting, the form and situation of building, openings, shading devices, Spatial organization	Opening (position, size), wind catcher, connective and evaporative cooling	Cooling, evaporation, humidify the space	Climate appropriate, local (available in the region), economic	Courtyard/Wind catcher/Iwan/ water ponds/Hozkhaneh/Yakhchal	Windows (with colorful glasses)/water/material
Sustainable Principles	Integration, Precaution	Equity	Precaution-Shared responsibility	Participation, Shared responsibility	Shared responsibility	Integration
Passive Dwelling	Windows/solar energy	Ventilation with heat recovery	Air tightness	High isolation	Compact shape	-

In the passive house concept, incompatibilities and failures in terms of sustainable design can be highlighted in terms of functional-aesthetic sustainability harmony and conceptual design process (Van Moeseke, 2011). In this sense, the traditional house's environmental, climatic and social harmony and integrity might serve as a complimentary model for modern passive dwellings. Thus, by developing answers to the inadequacies of physical needs with socio-cultural values in the passive house concept, the possibility of this concept as a sustainable approach in both functional and aesthetic dimensions terms is strengthened (**Table 4**).

On the hand, the majority of passive house research has focused on strategies and procedures for new buildings. However, retrofitting of existing buildings is extremely important for sustainable development and the conservation and use of natural resources, minimizing the use of mechanical energy for heating and cooling and improving the physical and aesthetic comfort of building occupants, and enhancing low-energy architecture. The important focus of this study is to identify passive design strategies that can be adopted to different climatic regions that will contribute not only to new buildings but also to the retrofitting of existing buildings and houses, taking into account traditional tactics and climatic and environmental characteristics.

4.1. Creation of contemporary interiors

Sustainable design concepts should be followed throughout the design and construction process for new buildings. Various climates require different circumstances to adapt and sustain, so the sun, wind, rainfall, and humidity of the location must be addressed while constructing buildings. In this sense, all design and construction decisions such as the form of the building, the addition of sustainable elements, interior space organization, openings and shading elements and material use should be considered, as well as the building's relationship with the urban fabric in terms of climatic and environmental characteristics, positioning on the land and harmony with the environmental design. The sustainable strategies for creating of contemporary passive houses in various regions based on climatic design of vernacular Iran houses can be listed and summarized as below (**Table 5**).

Table 5. Passive design strategies for new constructions in hot, cold and humid climates.

Key Passive Design Strategies	Building orientation/form	Building envelope	Natural ventilation	Daylighting and shading	Material	Architectural elements
Hot Climate	Inward oriented, central courtyard, located on the east-west axis, the summer living quarter biggest (facing north)	Minimum opening in external wall of the building (except entrance), Opening toward mild and humid areas (toward courtyard with water and plant)	Courtyard with water and plant	Solar shading panels	High thermal capacity construction materials, thick walls	Basement, veranda, often wind tower
Cold Climate	Inward oriented- around a central courtyard, the winter living quarter biggest facing south, service areas toward north, east and west.	Large opening facing south, little openings toward north, east and west.	Minimize ventilation with effective materials and openings.	Maximum use of solar energy with little or without veranda and shading elements	High thermal mass construction materials, thick masonry walls	Solar panels, basement

Table 5. (*Continued*).

Key Passive Design Strategies	Building orientation/form	Building envelope	Natural ventilation	Daylighting and shading	Material	Architectural elements
Humid Climate	semi- inward oriented, south of building toward sea or wind	Effective opening all around the building and courtyard	Cross ventilation, wide balconies, large openings facing sea air, wind catcher	Horizontal and vertical Shading elements, Big and spacious verandas	low thermal mass construction materials	Deep awnings and verandas, wind tower, without basement

4.2. Retrofit and renovation of existing buildings

In terms of sustainable development, new buildings as well as existing buildings should be retrofitted and renovated using passive house strategies. In this case, some principles such as the orientation and layout of the building cannot be changed. In this regard, enhancing the energy efficiency of dwellings and improving them based on climatic conditions can be accomplished through internal space organization and facade renovation. First and foremost, the building's environmental and climatic parameters, as well as the weather conditions during the summer and winter months, should be determined. As a result, it is critical to capitalize on favorable circumstances while minimizing and preventing adverse ones.

In hot and humid climates, it is important to optimize the prevailing wind and shade while allowing as little sun to enter the interior as possible. In this regard, it is vital to employ solar energy for cooling and ventilation through various methods such as solar panels. However, in cold climates, maximum use of the sun and maximizing the thermal mass of buildings is the most critical point. In this sense, retrofits can be made according to **Table 6** for renovated buildings.

Table 6. Passive design strategies for retrofitting existing structures in hot, cold and humid climates**.**

Key Passive Design Strategies	Building orientation/form	Building envelope	Natural ventilation	Daylighting and shading	Material	Interior space organization
Hot Climate	–	High quality insulated glasses for windows, remove west-facing windows, use south-facing windows with horizontal louvers and pergolas	Maximize using prevailing wind, water and plant element, Utilize solar energy to mechanic cooling	Integrate solar shading, minimize direct daylighting, using structures like pergolas, louvres, and screens, add northern side apertures, customize the window size	Interior materials change to high thermal mass, smart glass, solar control double & triple glass for openings	The main functions (living areas) are located towards the north and the service areas towards the other directions
Cold Climate	–	Integrate solar panel, high quality insulated glasses for windows without air tightness		Maximize using of solar energy, customize the window size	Interior materials change to high thermal mass, Insulation	The main functions (living areas) are located towards the south and the service areas towards the other directions
Humid Climate	–	Integrate solar shading, cross ventilation	Utilize solar energy to mechanic cooling	Integrate solar shading, add northern side apertures, customize the window size	Interior materials change to low thermal mass	Adding semi open areas such as veranda around building

4.3. Enhancement of passive design with vernacular elements and technology

4.3.1. Integrating solar gain and shading into passive house architecture

Effective solar shading plays a crucial role in the design and functionality of passive houses. In these buildings, incorporating shading elements such as exterior shutters and awnings can significantly reduce solar heat gain and increase energy efficiency during the hot months. Shading elements can be equipped with automatic controls that adjust shading according to the position and intensity of the sun, reducing heat gain and improving energy efficiency.

These elements can also provide the energy of cooling and air conditioning systems, preventing the solar energy from entering the interior in hot regions and during warmer months. In this manner, shading elements used in passive dwellings can also act as solar panels ensuring functional comfort. These panels might likewise absorb sunlight during the day, fold at night to release stored heat, and reopen the next day (**Figure 4**).

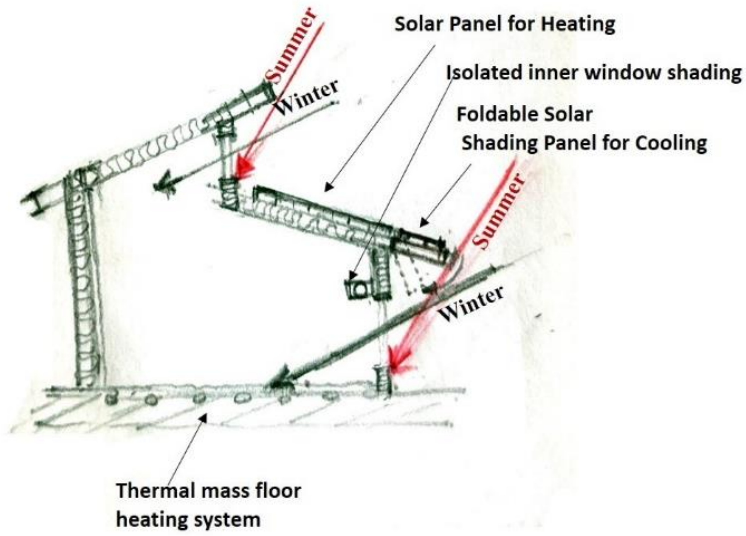


Figure 4. A foldable shading panels combined with solar panels in passive house.
Source: Author.

Effective solar shading is critical to the design and performance of passive houses. Buildings that strategically include shading components such as outside louvers and awnings can greatly limit solar heat gain and reuse during the warmer months. Furthermore, natural shading devices, such as leaf trees, could be a useful alternative for residential homes.

In terms of sustainability, the color, texture and material used in these shading elements can help to provide aesthetics comfort if they are designed in accordance with the cultural and social values of the region. Hence, functional and aesthetic sustainability are accomplished together in terms of cooling, lighting and ventilation in contemporary buildings.

4.3.2. Advanced material in passive house architecture

1) Buildings could be designed using advanced environmentally friendly insulation materials that minimizes heat transfer and reduces the need of air conditioning. New structures should ensure its potential of thermally efficient with the least amount of energy usage with thermal insulation. The sustainability and renewability of the resources, such as recycled content, natural fibers, or bio-based materials, can be evaluated in the case of eco-friendly insulation materials. In order to ensure the economic and environmental components of sustainability, the use of natural materials, such as vegetal fibers or products made from recycled industrial and agricultural waste, demonstrate particularly attractive features for enhancing thermal comfort (Ajabli et al., 2023). Utilizing locally sourced materials increases sustainability and efficiency while reducing the need for material processing or transportation, resulting in a comfortable indoor climate.
2) Windows are a building's weakest point in terms of energy efficiency and thermal resistance. In this regard, it is crucial to determine techniques for both absorbing solar energy, minimizing and blocking its access into the interior through appropriate window and glass choices in various climate zones.

Lower *U*-values indicate less heat loss in the winter and less heat gain in the summer. Investing in building components with low *U*-values, such as well-insulated walls, roofs, windows, and doors, can dramatically reduce the amount of energy used for heating and cooling. High-performance and energy efficient glasses are coated with various metal oxides that reduce excessive absorption and transmission of solar heat. This reduces a structure's energy cost and also its carbon footprint. This type of glasses also improves thermal comfort with a sense of openness for people working inside. Solar control films (SCFs), while utilized on glazing systems, can reduce heat gain, annual energy consumption, and peak demand load (Teixeira et al., 2020).

Lower *U*-values signify reduced heat loss during colder months and decreased heat gain during hotter periods. By investing in building components with low *U*-values, such as well-insulated walls, roofs, windows, and doors, the amount of energy required for heating or cooling can be significantly reduced. High-performance and energy efficient glasses are coated with various metal oxides that reduce excessive absorption and transmission of solar heat. The use of such glazing improves thermal and functional comfort while reducing building's energy costs and carbon footprint, as well as enhancing user aesthetic comfort by creating a sense of openness and spaciousness.

4.3.3. Technological systems combined with wind catchers in passive house architecture

In this system culverts as underground water channels like Qanat in wind catcher of vernacular architecture, carrying pipes for evaporation and humidification. Water supplied through concrete tunnels (culverts) improves indoor air quality and ventilation through convection and evaporation system (**Figure 5**) (Vrotsou and Glad, 2021). In order to reduce soil and air pollution, stone dust and chips could be used in the construction of these concrete tunnels.

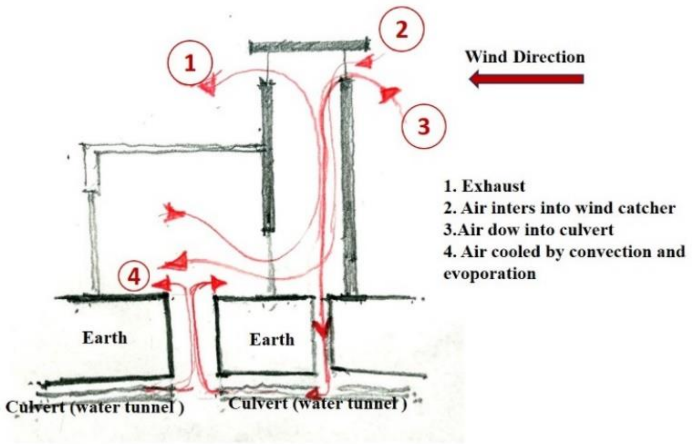


Figure 5. System of wind catcher combined with underground energy**.**
Source: Author.

Wind catchers can have a major impact on reducing cooling loads and providing the necessary ventilation rate for structures. As a result, this illustrates that wind catchers have the potential to be used in modern passive buildings. However, traditional windcatchers were advantageous, but had some shortcomings, such as dust and insects entering inner rooms through shafts or lower efficiency of towers especially with a low velocity of winds (Omer, 2008). In this aspect, the integration of new technologies and innovative designs eliminates some of the shortcomings of previous wind towers:

- Windcatcher with a circular and rotating head with transparent materials to cross daylighting to buildings.
- Air pressure + water: In the first step, air enters a wind catcher via a pressure difference (down-draft evaporative cooling (PDEC) system). Then in the second step involves spraying water. Windcatchers with a wet surface, as well as windcatchers with a pump system wetted blades and grid pads on the column's entrance, perform better at low velocities. The kinetic energy of the sprayed drops is released into the air at the last stage. Depending on the climate of the area where the wind catcher will be installed, different applications for the water spray system may be required. Humid climates are not as ideal for this technique as dry ones are (Kheirkhah Sangdeh and Nasrollahi, 2020).
- Wind catcher coupled with solar chimney: In this way, a one-sided windcatcher integrated with a solar chimney provide reasonable thermal and airflow conditions without the need of wind force. South facing concrete wall acts as a thermal mass for solar chimney separates the windcatcher and the solar chimney. In the summer, this system provides ventilation and cooling from the heated air in the chimney, while prevents heat loss with closed apertures on the heading of tower and directs it indoors in the winter (Moosavi et al., 2020).

By integrating vernacular sustainable solutions and strategies with modern technology and materials, the user's indoor comfort level and the conservation of the natural environment and resources can be enhanced (**Figure 6**). The model presented here emphasizes a number of key design elements, as passive house design involves the efficient use of natural energy resources, the minimal use of mechanical resources and ensuring the user's long-term comfort. In this sense, contemporary dwelling design varies according to different climatic, environmental and spatial characteristics. The model focuses on the utilization of daylight and natural lighting, solar energy and shade, wind and natural ventilation, and the selection and application of sustainable materials based on their properties.

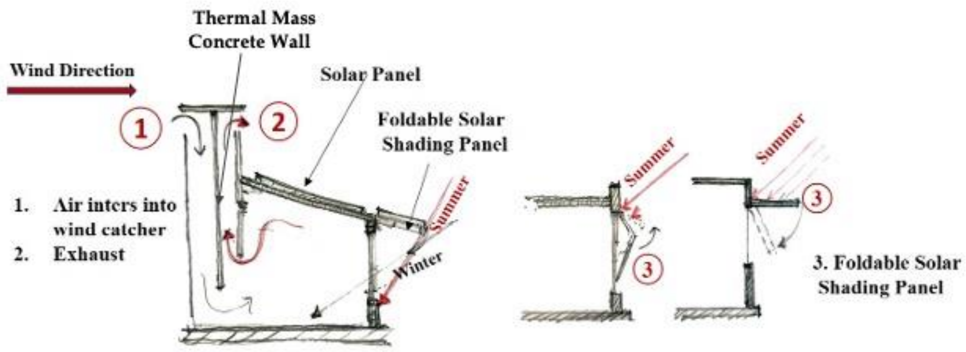


Figure 6. Contemporary model of passive house combined of vernacular strategies, solar shading panel and wind catcher as solar chimney.
Source: Author.

Overall, climatic design and energy efficiency in today's dwelling can be achieved using one or a combination of the methods described. In this context, the climatic and environmental features, summer and winter weather conditions and the characteristics of natural resources such as wind and sun, and their integration into the building's design, are critical.

5. Discussion

The reduction of utilization, reuse, and recycling of energy resources constitutes the three principles of sustainable development and architecture aimed at enhancing the indoor environment of buildings (Ghobadian, 2021). A building is sustainable if it contributes to the sustainability through its environmental, physical, economic, social and cultural features. In this sense, building ought to enhance user comfort and protect environmental values at the intersection of design and functioning by incorporating its technical and aesthetic systems. On the other hand, mechanical methods and technologies have been used in modern structures to provide indoor user comfort without regard for climatic factors. The aesthetic characteristics are independent of cultural and social values, and a new perspective has evolved that represents contemporary times achievements. Construction materials such as glass and metal provide this aesthetic understanding, whereas building shells induce heat loss in the winter and they transport sun to the inside during the summer.

As a result of the research, the building's orientation and form, the design of the building envelope, the materials used, and the organization of the interior space were evaluated for the efficient use of solar energy and natural heating, cooling and ventilation in various climatic conditions, for new buildings and improving existing buildings. Passive strategies for today's dwellings can be determined using traditional methods.

Additionally, the environmental, economic, social, cultural and technological transformations took place in different periods caused physical and functional changes of houses. Population increases, global warming, and changes in climatic conditions, as well as advancements in urban fabrics, changes in user requirements, behaviors, and lifestyles brought about by modern life, have all influenced the design and use of houses (**Table 7**). According to these changes, there may be some deficiencies and inadequacies in the process of adapting local methods and architectural elements to today's passive house design.

Table 7. Differences of vernacular and contemporary houses due to environmental, economic, social and cultural changes.

Content of Changing Aspects	Vernacular House Features	Contemporary Dwelling Features
Social/cultural	Patriarchal extended families	Independent nuclear families
Economic/cultural	Single-story detached	Multi-story apartments
Social/Environmental	Inward-looking courtyard houses	Outward-looking residential complexes with a shared courtyard.
Economic/Social	Functions: Living, socializing and leisure area	Function: Living
Environmental	Separate open and green zones for each house and family	Shared green space and open areas for multiple families and apartments
Economic/cultural	Hours of active use of the house: All day	Hours of active use of the house: The part of the day

The physical attributes of modern residences, including their design, dimensions, location, and the features of indoor, outdoor, and semi-outdoor areas, as well as their interaction with the environment, economic factors, geographical context, and social and cultural values, are indispensable to change according to the traditional one. For example, today's economic and social conditions have caused all family members to work outside, and in this case, houses are generally used on weekdays outside working hours. Cultural and social reasons have led families to spend time in different shopping, socializing and recreational areas outside at the weekend. In this case, unlike traditional houses, modern dwellings are used as simple living spaces, with the exception of functions such as socializing and gathering, therefore they are usually empty for half the day (**Table 7**). Thus, in passive house concept, energy resources used by automated and technological systems for needs such as cooling, heating and ventilation can accumulate during the other full part of the day.

Combining technological methods and materials with traditional approaches can provide more sustainable solutions to today's spatial and environmental needs. Technological developments have resulted in new approaches, solutions, material selection, and application variation. In this sense, when the principles and strategies in vernacular sustainable architecture come together with today's technology, a modern passive house model can emerge both in areas where traditional methods are insufficient and by solving the inevitability of using technology.

In this sense, vernacular architecture, which provides holistic sustainability, can provide a modern passive house model when technology and today's user needs coincide. As a method, this approach can be sustainable without risking the ability of future generations to meet their requirements while providing environmental, functional, economic, social, cultural and aesthetic comfort for today's users (**Figure 7**).

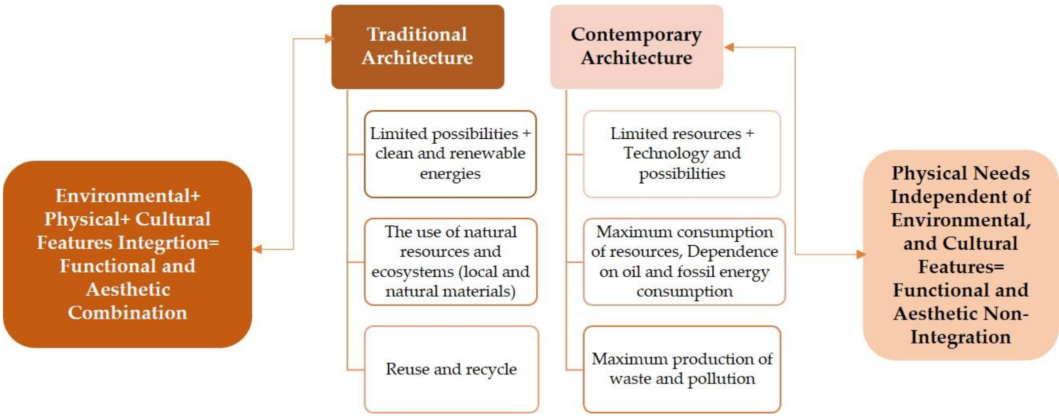


Figure 7. The impact of life cycle of traditional and contemporary architecture on functional and aesthetic comfort.
Source: Author.

This study proposed a vernacular sustainable principles and creative and local solutions which provide a comfortable living environment, consume less energy and cause less pollution than the new ways of construction for contemporary new constructed and retrofired of existing dwellings. This study could provide a framework and methodology for future studies. In future studies; the effect of solar and wind energy as natural resources integrated with technology in contemporary buildings with various functional and aesthetic needs to be investigated. In addition, to achieve a more appropriate solutions due to particularly limitations of traditional principles in providing favorable thermal, ventilation and lighting conditions in extreme climates needs.

6. Conclusion

Consequently, this study uncovered and analyzed a combination of several passive strategies of vernacular housing in various climatic conditions in Iran which could be references for functional and aesthetic comfort of contemporary passive dwellings. Vernacular architecture has sustainably adapted to climate by devising innovative local solutions that offer a suitable living environment, utilize less energy, and generate less pollution than contemporary construction methods.

With changing climate conditions and global warming, architects are looking into passive design techniques to mitigate rising temperatures. To deal with the extreme temperatures in hot and dry places, a variety of strategies can be utilized, including preventing direct sunlight, utilizing cooling devices, improving ventilation and airflow, and injecting moisture to dry air.

Efficient use of natural resources and reduction of mechanical systems for thermal heating, cooling, natural ventilation, shading, and daylighting of vernacular houses improves user comfort. Climate and weather conditions are seen as the foundation of human life and activities in traditional architecture, resulting in physical and aesthetic features of buildings. Accordingly, passive design solutions, should be socially, culturally and aesthetically responsible as well as functionally and environmentally beneficial. In this context traditional architects have implemented a wide range of strategies into buildings based on environmental and climatic conditions to ensure the user's spatial and aesthetic comfort. These strategies can be examined and applied in modern designs to reduce energy consumption and produce a clean environment. These traditional techniques can be applied to both new buildings, as well as options for existing and renovating interiors. In cases where traditional methods are insufficient, they can be applied by integrating with technological solutions involving the use of new technologies, inventions, systems and eco-friendly materials for passive house concept.

Conflict of interest: The authors declare no conflict of interest.

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