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Studying and Proposing an Energy-efficient Residential Design for Kashan with a Hot and Dry Climate

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Abstract

It seems that architectural design has an important effect on energy consumption. When designing the best energy-efficient form, the arrangement of rooms and the positioning of outer walls are crucial considerations. This study aims to determine the optimal form for reducing energy consumption by examining the influence of environmental phenomena on climatic design and considering traditional lifestyles. Thus, Kashan is selected as a case study, and a study is conducted on the principles of climatic design and the nomadic lifestyle of Kashan's historical buildings. Two different designs for Kashan residential buildings are presented based on collected data. Findings demonstrate that utilizing Kashan City's traditional and historical pattern of residential design and its central courtyard can help reduce energy consumption by 23% to 34%. The traditional design and preference for a nomadic lifestyle result in seasonal mobility inside the house's spaces, which can be reduced by 38.1% using appropriate openings. It is also clarified that by utilizing and following the patterns of moving between spaces and using them seasonally, saving 4-15% in energy consumption is possible.

Keywords: climatic design; nomadic lifestyle; hot and dry climate of Kashan; energy consumption

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1. Introduction

Generally, buildings designed according to climatic principles can reduce energy consumption for heating and cooling. Long-term economic considerations can justify climatic design for users and investors. Many of these techniques are cost-free and can be easily implemented in standard buildings; however, stakeholders, designers, and builders must know the benefits of climatic design. The design of the building, according to the climatic conditions of the project site, has other advantages. Rather than putting additional strain on the heating and cooling systems of the building, it improves the thermal comfort conditions of the building without causing noise, disturbance, or environmental consequences. When specific conditions are met, the least pressure is applied to the cooling and heating equipment while thermal comfort conditions improve. Climate-sensitive architecture promotes a

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healthy and aesthetically pleasing living environment for humans and protects the environment from the negative effects of excessive energy consumption. Various strategies are employed to implement the climatic design, including the correct arrangement of spaces that face natural light, the appropriate level of openings, and the appropriate use of natural light, greenhouses, porches, and central open courtyards. These solutions provide an environment in which the human and natural environments are balanced.

The topic of climate design is typically not difficult to understand. Physical and psychological comfort depends on the thermal energy equilibrium between the building and its occupants. According to Himeur et al. [١], four physical principles govern heat transfer: conduction, displacement, radiation, and evaporation. Natural thermal and cooling energy sources include the sun, wind, precipitation, and the resulting air and ground temperatures.

On the other hand, the architectural design of a building is the result of a complex combination of multiple factors, such as climate, structure, performance, and cultural-social issues. These factors contribute to the building's final form. In addition to displaying the building as a whole, the external form and shell also determine the building's first appearance. This research investigates the climatic aspect of the building's form. Most energy transfer in the building occurs through the exterior form and shell. Given the necessity and significance of the energy crisis in recent years, the increasing consumption of fossil fuels as limited energy sources, and their impact on the environment, this study examines the design of an energy-efficient residential building designed to suit the hot and dry climate of Kashan.

Utilizing the proper form improves not only the building's energy efficiency but also the thermal comfort of the interior environment. An important consideration in the design of a building is the use of space. Therefore, if it is possible to adapt the way of life in the space according to the historical and traditional pattern and to adjust the location in the seasonal cycle of the year in spaces that are suitable for that season, integrating the designed form and the way of life will produce a better result. This research investigated passive solutions for reducing energy consumption in buildings by designing a sample residential building in Kashan's hot and dry climate, following the principles of form configuration in these climatic conditions and the nomadic lifestyle in the seasonal spaces of the house. The amount of energy consumption in this sample is compared to the average amount of energy consumption in a commen design. This study investigates how a residential building model can be more energy efficient in Kashan's hot, dry climate and how a nomadic lifestyle, which involves seasonal movement within the home, will affect energy consumption.

2. Materials and methods

Analytical and documentary methods are used in the research. First, a library search is conducted to extract a framework for designing an energy-efficient model for a residential building in Kashan's hot and dry climate. Then, the extracted principles of analysis, climatic design, and nomadic lifestyle are used to design a residential building in Kashan. Then, its thermal performance is evaluated by modeling in Design Builder software (version: 21.8.16). This software's modeling engine is called Energy Plus, one of the most accurate energy modeling tools available for conducting a thermal study of a building's location, physical attributes, and performance. However, the error rate in real-life situations is about ±14%[2]. The difference in numerical energy consumption is reliable and does not differ from the actual amount. Thus, this study focuses on analyzing architectural design regarding energy consumption. The data from three distinct modes are compared: the first mode, the living room, the first design option; the second mode; the southern settler, the second design option; and the third nomadic settlement state between the northern and southern settler. The input dates for this evaluation are the principles of climatic design, the nomadic lifestyle of traditional houses in Kashan, and the Meteorological information of Kashan.

3. Background and theoretical framework of the research

In Iran, climate-sensitive building design principles were studied in the 1960s [3, 4], focusing on issues such as the use of airflow in ventilation and the application of radiant and evaporative cooling, and the use of solar heat [5]. With the advancement of technology, the modeling of buildings from the perspective of compatibility with the climate commenced, such as the modeling of housing compatible with the climate for the city of Chabahar [6] and the study of the climate and architecture of the schools of Isfahan [7]. Islami et al. [8] investigated the architectural principles of native housing in hot and dry climates, taking into account the effect that the building's form has on the thermal comfort of its residents. The results indicated that warm and dry local housing climate patterns significantly impact the thermal comfort of building occupants [9]. Qulinejad et al. [10] addressed the standardization of sustainability in the formation of elements of hot and dry climate architecture and the analysis of global sustainability issues. They concluded that such divisions could not necessarily be used in Iran's hot and dry climate. Instead, climatic conditions, regional priorities, and other rules and standards developed in Iran should be the deciding factors for action. Also, Zamani et al. [11] determined that courtyard design factors such as proportion, orientation, geometry, opening features and materials, and components such as shading devices, vegetation, and water pool were effective in energy consumption, internal and external temperature, solar radiation, and natural ventilation in various climates. Taghizadeh et al. [12] examined the influence of climatic measures based on seasonal movement in traditional Iranian medicine on human health and its effect on the spatial organization of traditional Iranian residential architecture. Her objective was to analyze the origin of the climatic knowledge of traditional architects and determine the role of the medical foundations of climatic measures based on seasonal movement. In a study examining the effect of the building's external shell on energy consumption, researchers modeled a residential home using the Design Builder software. They investigated the effect of the thermal performance of various building shell components on energy consumption. The findings of this study indicated that the performance of the wall in terms of its energy-saving potential was high. In contrast, window performance was lower, and roof performance was limited [13]. For example, on sunny days, the southern walls of the building received up to 75% of radiant energy; on the other hand, on cloudy and semi-cloudy days, it reached 7% and 18%, respectively [14]. The green building design is one method of reducing energy consumption. Geng et al. [15] reported a significant gap between designed and operational energy consumption, and many green buildings saved less energy than expected. In a study on optimizing energy consumption in residential facades, a method was presented for finding the optimal design pattern. Tahbaz et al. [16] conducted field research in Kashan's historical context and discussed how natural forces could benefit living spaces via lessons learned from the climatic architecture of its. In his research, Heidari [17] identified the deep courtyard as the optimal building design for a desert climate. He considered small courtyards an excellent thermal regulator since they provide shade during the day. Another study revealed the role of renewable energy consumption in shaping environmental quality. In their view, abundant natural resources and foreign direct investment contribute to the degradation of the environment [18]. In addition to reducing pollution and energy consumption, using renewable energy or solutions to control energy consumption could significantly impact economic prosperity [19]. Other research examined the experimental process of living in an Iranian home and how people move between different spaces to achieve comfort [20]. The importance of the control of incoming radiation has been studied in another research. According to the findings, the shading of adjacent buildings could decrease the interior temperature by more than 2.5°C [21]. Behbood et al. [22] investigated climate-responsive design solutions in Kashan's hot and dry areas on three levels. The distance between buildings, narrow urban environment, and irregular streets as a macro strategy was considered in the first level. The third level focused on medium-scale strategies, building forms, building covers, self-efficacy of materials, and optical and thermophysical properties of building shields. Finally, micro-scale strategies were included in the third level. Sustainable materials have been the subject of a wide variety of research, including studies focused on the role of materials in reducing energy consumption and their effect on sustainable architecture. It is found that using native and smart materials increases building lifespans, reduces environmental pollution, and decreases energy consumption [23]. It has been widely reported that housing designs and climate classifications are influenced by factors such as the local climate, human thermal comfort conditions, and architectural design criteria [24]. A comparative study was conducted by Alemi et al. [25] regarding a specific building in Kashan with an emphasis on the importance of the external shell of buildings in determining energy consumption. The results indicated that a building with no thermal insulation or incoming radiation control could consume more than 33% of primary energy compared to a building in a controlled state. The effect of resident behavior and adaptability on energy consumption was also studied in another study. It was noted that it was necessary to raise awareness about the impact of adaptability on energy consumption [26].

International Energy Agency and the energy balance sheet indicate that while Iran has 1.08% of the global population, its energy consumption is 1.1 times the global average in the energy consumption sector. Since most of this consumption is in the non-productive sector and is accompanied by high losses, there is room for reflection, and a reduction is necessary [27]. For this reason, this research focuses on two crucial aspects of residential building design: optimization solutions for energy consumption and energy requirements for buildings.

3.1. Optimizing Energy Consumption in Buildings

Utilizing a passive solar system can reduce the costs associated with heating and cooling the home [28]. Residents also enjoy a sense of tranquility, stability, and environmental harmony. Through the most efficient utilization of radiant energy, passive solar systems adapt the building to its environment and provide comfort to occupants for the length of its useful life. This system receives solar energy directly, indirectly, and isolatedly [29]. Direct receiving allows direct sunlight to penetrate interior spaces, while indirect receiving utilizes thermal storage materials. In this method, the sun's rays are absorbed and stored in materials, then dispersed and transmitted via conduction or convection. In isolated receiving systems, radiation stores energy in a chamber that leads to either open or closed spaces [30]. Energy-efficient buildings are designed using passive and active systems. The following should be considered in the design of a building:

Table 1. Zero energy building design methods

	Energy-efficient design methods
Passive design	Paying attention to the position of the sun, the appropriate shape, the appropriate color, the appropriate distribution of interior spaces, the appropriate proportion of open and transparent spaces, an entrance that is protected from wind flow, the correct selection of materials, the appropriate thermal capacity of materials, and the use of thermal insulation, the application of shadow volumes. Size, use of awnings and sunshades, utilization of energy-saving solutions like the internal blue wall, thermal wall, or Trombe wall, and greenhouse.
Active design	Utilizing photovoltaic cells, solar collectors, ventilation and air circulation fans, wind turbines, fuel cells, solar water heaters, and heat pumps.

An auditor can utilize various calculation and simulation techniques to analyze energy consumption and estimate the effectiveness of energy-saving solutions. The available energy analysis methods vary greatly in complexity and precision. To select the most suitable energy analysis method, the auditor must consider several factors: speed, cost, changeability, reproducibility, flexibility, precision, and usability [31].

Due to the country's economic and social conditions and the cost of energy carriers, many energy-saving plans are not deemed cost-effective; therefore, inexpensive methods for reducing energy consumption in buildings are of particular significance. Architectural design methods that reduce energy consumption are less expensive and more environmentally friendly, even if energy prices increase. The optimal orientation for most building surfaces is the direction that receives the most winter and the least summer sunlight. In winter, the south face of a building is exposed to solar radiation three times more than other faces; in summer, it is the opposite. As the sun is lower in the sky in winter, it shines at a lower angle. Its radiation strikes the southern facade from a nearly perpendicular position, so it receives less sunlight. In winter, the heat absorbed through south-facing glass walls is greater than the heat lost through this glass front in almost all climates [32]. The window's dimensions dictate the amount of direct solar radiation. Suppose the room is overheated on a sunny winter day. In that case, the solar system will operate less efficiently if the windows are disproportionately large to the heat loss or if more heat is absorbed than necessary. On a sunny day in December or January, the optimal amount of solar energy a room absorbs is such that the interior temperature remains constant at 21 degrees Celsius [33]. Proper planning and design for energy absorption are required to optimize energy consumption through the window. This implies that the windows should be designed to absorb the maximum amount of solar energy possible. To achieve this, the building's form and orientation are essential. In general, northern and southern positions are preferred, while eastern and western positions should be minimized. This facade is the best for accessing natural lighting because it receives abundant and uniform sunlight and can control the excessive heat absorption from the summer sun with protrusions. While the north face receives less natural light, its relatively constant access to sunlight and absence of summer sunlight makes it the second most desirable building orientation. Northern windows' high net heat rejection is considered a deficiency in these facades. In both east and west orientations, sunlight is only available for half the day, making it more challenging to design an optimal lighting system. There is an excessive amount of unnecessary summer heat absorption in these orientations (especially the western orientation), while in winter, it does not contribute significantly to static heating. It is, therefore, necessary to reduce the size of the eastern and western facades [34].

3.2. External shell of the building

The exterior shell of a building consists of the surfaces that separate the interior space from the exterior environment. These surfaces include walls, roofs, floors, doors, and windows. Among its important functions are balancing the weather conditions of the exterior environment, providing the necessary lighting for the interior, and facilitating visibility and visual communication with the exterior environment. Due to its interaction with the exterior environment, the building shell plays a significant role in adjusting to the weather, ensuring the residents' comfort, and controlling the amount of energy loss. Accordingly, a building's design and materials have a significant influence on its response to environmental and climatic conditions. It is necessary to evaluate the thickness and material of a building's exterior shell in order to determine the building's thermal comfort range.

By isolating the interior space from its surroundings, the building's roof and exterior shell prevent environmental factors from directly influencing the interior. The following table illustrates the energy loss contribution of each building shell component.

Table 2. Energy losses from the building shell [10]

Walls	25%-35%
roofs	10%-15%
floors	5%-10%
doors and windows	15%-25%
air penetration	10%-20%

Each wall layer has a unique temperature due to heat transfer. This temperature difference occurs because heat is stored within each wall layer and transferred to the adjacent layer. Therefore, each successive wall layer has less heat than the previous layer. As the outermost and largest surface of the building shell, the building façade plays the largest role in absorbing and transferring energy to the building. Thus, it is advantageous to choose facade materials according to the climatic conditions of each region to reduce the building's thermal energy exchange. The insulation layer in the exterior wall is a crucial factor in energy loss. Designers employ two techniques to improve the thermal performance of the insulation layer. The first method involves improving the properties of insulating materials, while the second, which is more commonly used, involves increasing the thickness of the insulation layer [35, 36]. Figure 1 shows the different factors involved in residential building design.

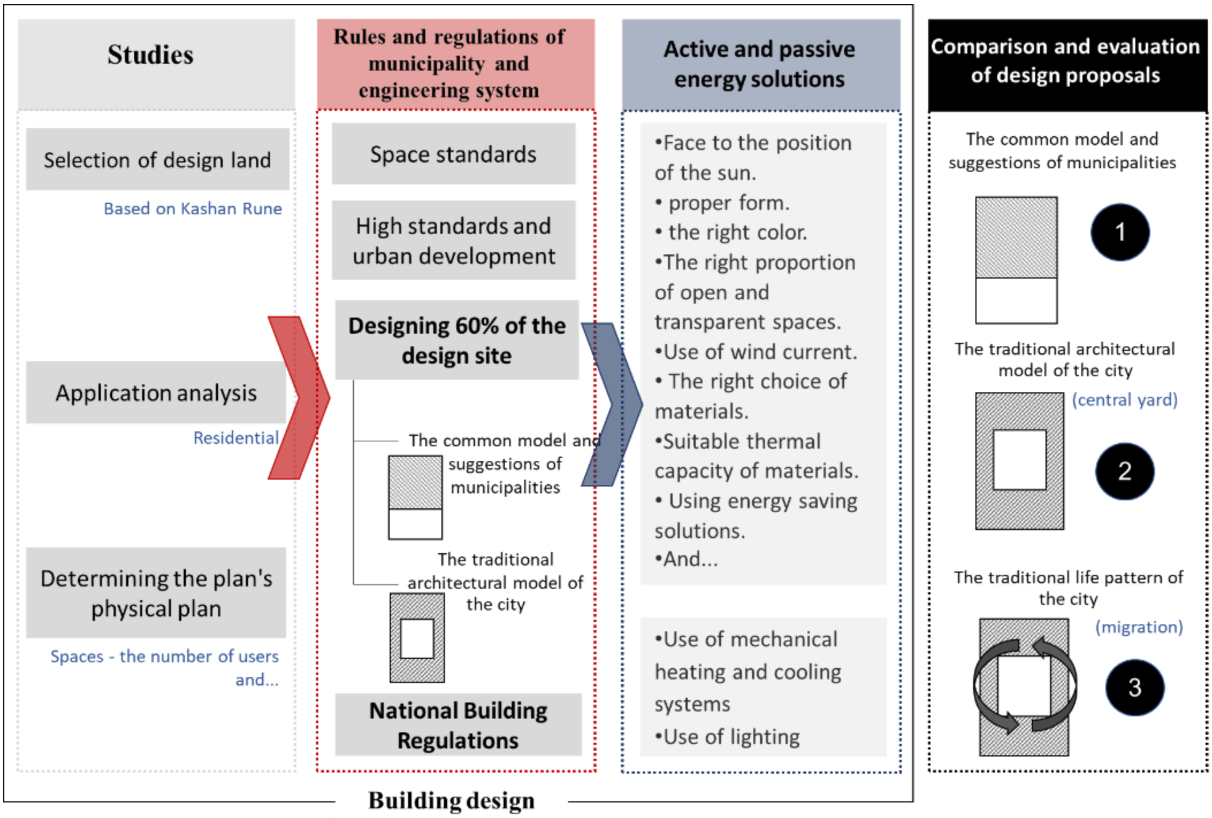


Figure 1: Examining the factors involved in the design of a residential building and the evaluation process of research design proposals

4. Designing a sample for evaluation

Kashan is located 230 kilometers southwest of Tehran, at a latitude of 23 degrees 59 minutes north and a longitude of 51 degrees 27 minutes east and 945 meters above sea level. Kashan is located in a climate zone with relatively cold winters and very hot, dry summers. Kashan's average temperature is approximately 19.8 degrees Celsius. The lowest temperature in this city is 4.9 degrees Celsius in January, and the highest temperature is 32.8 degrees Celsius in July. Kashan has an average relative humidity of 40%, which increases during the colder months and decreases during the warmer months. Figure 2 illustrates Kashan's humidity and temperature changes over a year. During the hot months of the year, such as August, when the air temperature is high, the airflow can act as a hot wind, stagnating bioclimatic conditions. Therefore, Therefore, it is necessary to prevent air entry into buildings during these months [37]. Figure 3 shows the changes in wind speed in a year in Kasahn. The design land is 300 square meters on Amirkabir Boulevard. On the east, there is a 6-meter passageway leading to Amirkabir Street; on the north, west, and south, there are neighboring properties. The site plan for this design is shown in Figure 4.

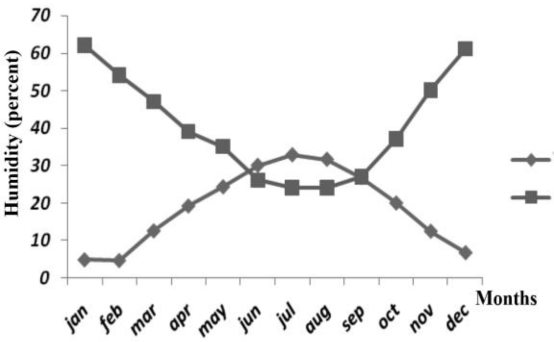


Figure 2. Humidity and temperature changes in Kashan [37]

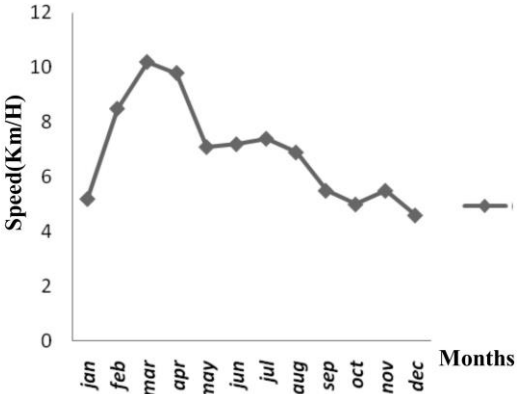


Figure 3. Changes in wind speed in Kashan [37]

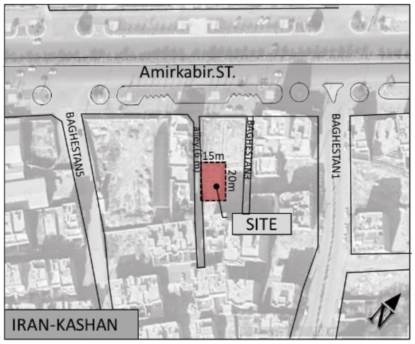


Figure 4. Location of the desired site

The design of this residential unit has been influenced by current urban laws, particularly the requirement of 60% plus 2 meters of land area for design, guidelines derived from theoretical foundations, and the city's identity and climate. Additionally, the building has been designed to include a central courtyard that reflects the traditional architecture of Kashan. The uses have been determined based on the requirements of a five-person family, and the uses on each floor of both options are identical. The land was chosen because its orientation or the plan's elongation corresponded to the general elongation of the historical houses in Kashan (Esfahani elongation). There are three different types of elongations or construction methods used in traditional Iranian cities: the Raste elongation (northeast-southwest), the Esfahani elongation (northwest-southeast), and the Kermani elongation (northwest-southeast) (east-west). The first option consists of one living room on two floors with a visual connection between them. Two living rooms (acceptable) are considered in the design of the second option, with the first living room located on the north side of the house and adjacent to the winter-use yard. The second living room in the southern portion of the building is considered higher (situated on the second floor with visual connection) than the first living room, which faces the sun and is utilized during the summer months. Considering the general behavior of the historical building, it is likely that migration occurs between the two settlements during the warm and cold seasons. In Figures 5 and 6, suggested plans for analysis are presented.

Figure 5. documents and proposed plans of the second option (traditional architecture of the region); Left to right: ground-floor plan, first-floor plan

Figure 6. Documents and proposed maps of the first option, From left to right: ground-floor plan, first-floor

5. Simulation and data specification

This study focuses on architectural design analysis in terms of energy consumption. In this regard, the data from three distinct modes have been compared: the first mode: the living room, the first design option; the second mode: the southern settler, the second design option; and the third nomadic settlement state between the northern and southern settler. The living room is a common space used continuously throughout the day and night in residential units. Design Builder version 21.8.1.6

and Energy Plus version 9.8 have been used for analysis and simulation. Design Builder software is a graphical user interface for the Energy Plus simulation engine. It can model the building from multiple perspectives, including physics, architecture, materials, shells, heating and cooling systems, lighting, and natural and mechanical ventilation. In addition, the capability of modeling the building's heating and cooling loads provides the user with dynamic information regarding heating, cooling, lighting, household appliances, and hot water consumption. To evaluate the internal conditions of spaces, Energy Plus software uses airflow modeling [27]. This method includes a series of airflow-connected points. The relationship between pressure and airflow at each point must be determined. Since this method assumes that air flows from one point to another, it is impossible to calculate air circulation within a thermal zone due to the simplifications made [28]. In general, a point in the center of each space is considered, and horizontal and vertical temperature variations are not evaluated.

A thorough assessment requires detailed specifications about the design, such as building models, weather data, materials, and other details. First, the building is modeled according to the design specifications in the modeling section. Weather data shows that Kashan's climate is hot and dry. Based on Figure 7, the dry temperature graph for Kashan reveals that the annual maximum temperature exceeds 40 degrees Celsius in June, July, and August.

In contrast, the annual minimum temperature drops below 0 degrees Celsius in December, January, and February. The city's temperature is generally outside the comfort zone throughout most of the year, as indicated by the graph of the air temperature. The Kashan weather file (IRN ES Kashan.407850 TMYx.2007-2021) in EPW format was used for simulations.

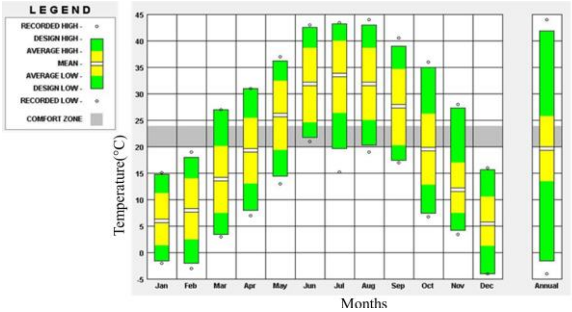


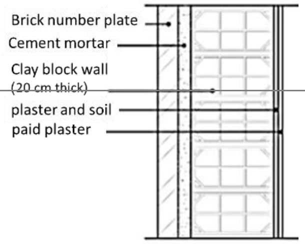
Figure 7. Dry temperature diagram of Kashan city.

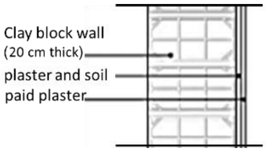
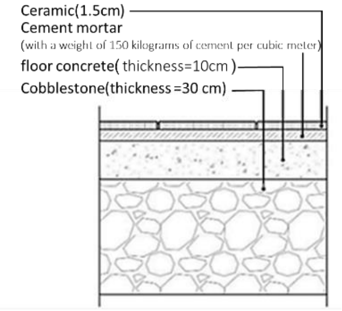
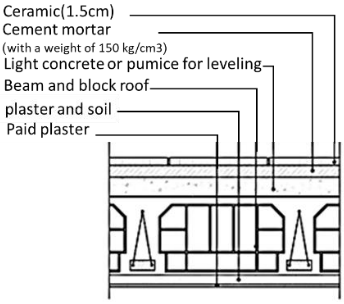
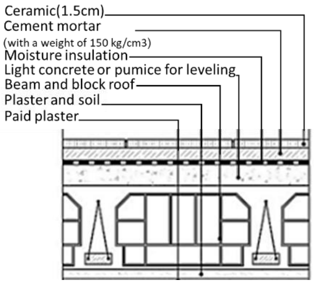
Another aspect that should be considered is building materials and details. Simulation for building with conventional walls and without insulation and the wall by the insulation according to the EC+ mode, topic 19 of the National Building Regulations [38], has been done according to Tables 3 and 4. In calculating the roof's thermal resistance, the negligible thermal resistance of waterproofing was omitted.

Table 3. Other characteristics of the residential building

Residential building insulation		Specifications
building blocks	value	Variable
Window	5.8	heat transfer coefficient (w/m^2.k)
Window glass	0.7	solar heat transfer coefficient (no unit)
Air penetration from the outer shell	1.5	times per hour

Table 4. Shell structure of a common residential building

Type of walls	Specifications			Heat transfer coefficient (without insulation)	Details
	Components	Thickness (cm)	Thermal resistance		
External wall	Brick number plate	3	0.03	1.52	

	Cement sand mortar	3	0.038		
	clay block (wall)	20	0.39		
	Plaster and soil	1	0.009		
	paid plaster	1	0.018		
Adjacent wall	clay block (wall)	20	0.39	1.7	
	plaster and soil	1	0.009		
	paid plaster	1	0.018		
The floor adjacent to the soil	ceramic	1.5	0.023	2.21	
	Cement sand mortar	3	0.038		
	Flooring concrete	10	0.05		
The floor adjacent to the uncontrolled space	ceramic	1.5	0.023	1.6	
	Cement sand mortar	3	0.038		
	Leveling concrete	5	0.096		
	Beam block roof with blocks	20	0.26		
	plaster and soil	1	0.009		
	paid plaster	1	0.018		
Roof	Mosaic	2	0.015	1.34	
	Cement sand mortar	3	0.038		
	Leveling concrete	10	0.192		
	Beam block roof with blocks	25	0.35		
	Plaster	1	0.009		
	paid plaster	1	0.018		

6. Analysis and discussion

The indoor thermal comfort criteria and the total energy consumption index, which incorporates lighting, cooling, heating, and hot water supply for visual and thermal comfort, serve as comparison criteria for evaluation indicators. The studied building with all construction details and operational issues was simulated to compare thermal comfort and energy consumption. Before evaluating and comparing the plans, the living rooms of the two designs were compared. Accordingly, the northern living room on the ground floor of the first plan was compared with the two living rooms on the ground floor of the second plan. The second plan designated the southern living room as the primary living space. According to meteorological data, the operating temperature in the living room of the first plan and the northern and southern living rooms of the second plan were measured on the coldest day of the year, December 18 or December 27, and the hottest day of the year, July 7. Figures 8 and 9 illustrate the results of this comparison on the coldest and hottest days of the year.

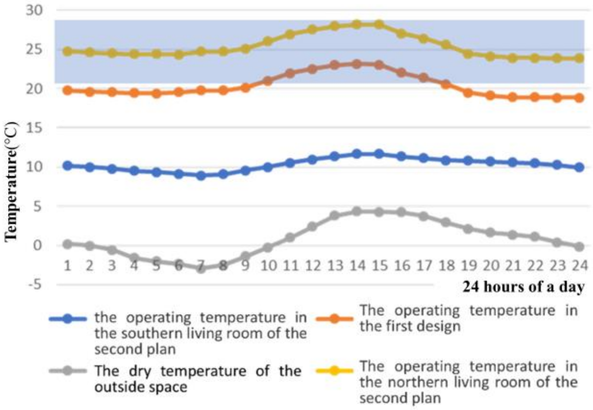


Figure 8. Comparison of the operating temperature in the north and south living rooms with the outdoor temperature on the coldest day of the year

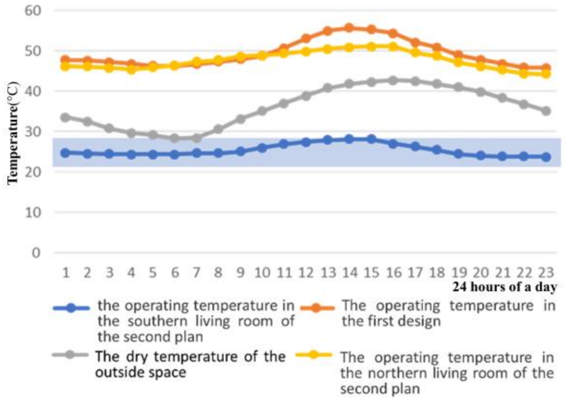


Figure 9. Comparison of the operating temperature in the north and south living rooms with the outdoor temperature on the hottest day of the year

In winter, the first plan's living room has a higher temperature than the southern living room (main) of the plan, while the second plan's northern living room has a higher temperature than the other two living rooms. Considering that both northern living rooms (i.e., the northern living room of the first plan and the northern living room of the second plan) face south and the internal temperature of the second northern living room is very close to the comfort range, this study illustrates how a south-facing orientation influences the internal temperature of a second northern living roomThe northern seats feature a central courtyard. Compared to other options, the principal living room of the second design (south living room), which faces north, has a cooler operating temperature during the summer. Figure 10 depicts the analysis of these rooms' annual energy consumption for lighting, cooling, heating, and hot water, despite their separate usage throughout the year. Residential cooling and heating account for most energy consumption, making it the most effective factor in reducing residential energy consumption. Comparing the cooling and heating loads of the north and south living rooms of the second plan to the living conditions of the first plan reveals the central courtyard's direct impact on the building's energy consumption.

Comparing the northern living room of the second plan with that of the first plan revealed a reduction of 0.3 kWh per square meter, or 0.01%, in heating energy consumption. By contrast, energy consumption in the southern living room increased by 1.3 kWh per square meter or 0.08%. Comparing the northern living room of the second plan to the living room of the first plan, 74.19-kilowatt hours per square meter, or 46.9%, and the southern living room of the second plan to the living room of the first plan, 110.55-kilowatt hours per square meter, or 70.0%, in terms of cooling energy consumption. In both modes, lighting energy consumption is reduced to a negligible level, and water heating energy consumption is reduced by 31.9% and 26.5%, respectively. It should be noted that in addition to the percentage reduction in energy consumption for lighting, cooling, and heating, the reduction is also significant. As each factor contributes to the total final energy, the load reduction resulting from the combination of the above factors will be decisive in evaluating the building. Since the building is heated by natural gas and cooled by electricity, the impact of the cooling load is greater than in other cases and has a significant impact on the final evaluation.

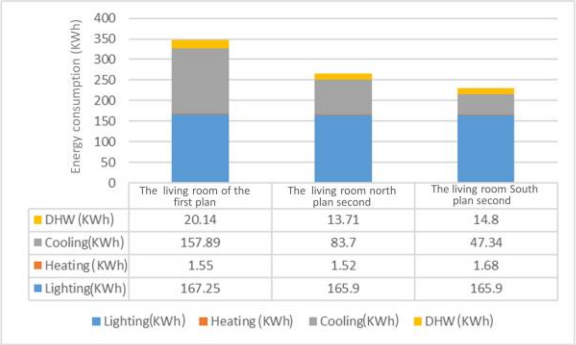


Figure 10. Comparison diagram of building energy consumption in three modes.

The high values of this building's insulation are converted to primary energy and compared to the building's kilowatt hours per square meter. This provides a more accurate assessment of the energy efficiency of the building's insulation. In Figure 11, the primary energy consumption among three different modes is compared. As shown in the diagram depicting energy consumption in three modes, it can be concluded that using only the north living room of the second plan is likely to result in 23.34% energy savings compared to only using the first plan. However, utilizing only the south living room results in 34.23 savings. The central courtyard design in Kashan reduces primary energy consumption by 23-34% compared to the 60% design based on municipal regulations (first plan). Two living rooms are designed in the second proposed plan, drawing inspiration from the architecture of the central courtyard in Kashan.

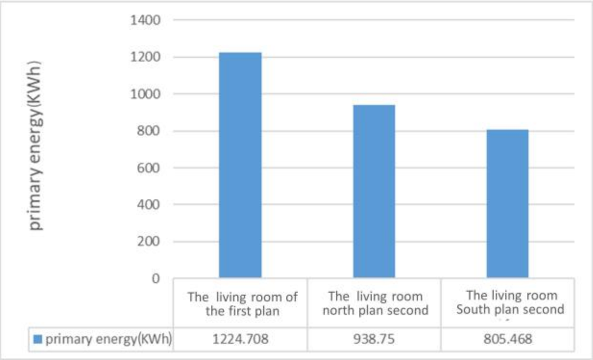


Figure 11. Comparison diagram of building's primary energy in three modes

The northern living room of the second plan is considered a winter living room, which is only utilized during the cold season to evaluate the effect of seasonal use on the building's energy consumption. As a result, this space only has a heating installation, and its cooling energy consumption is zero. Similarly, the living room to the south is considered a summer living space since it only has a cooling system and does not require heating. The annual energy consumption of these two spaces is then computed. A comparison is made between the energy consumption of this option and that of the standard option. It is impossible to compare the annual energy consumption of the north living room with the total heating consumption of the north living room and the cooling of the south living room, even though both rooms have nearly equal areas and volumes. This is due to the fact that the total area of the north and south living rooms is double the area of the northern living room. Further, since the studied space is used for living, energy consumption includes lighting, air conditioning, and heating. Figure 12 compares the basic energy consumption of two common living rooms and the winter-summer living room. Figure 13 compares energy consumption in two basic living rooms and the winter-summer living room.

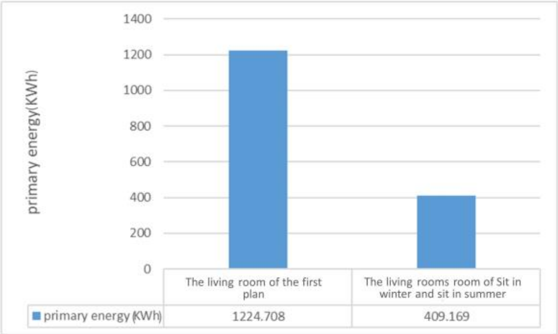


Figure 12. Comparison of basic energy consumption in two common living rooms and winter-summer living room

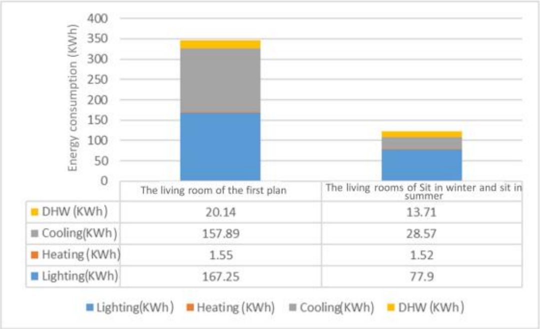


Figure 13. Comparison of energy consumption in two basic living rooms and winter-summer living room

The analyses reveal that the cooling sector consumes the most energy, reduced by 129.32 kilowatt hours per year, or 81.9%. Despite a slight increase in lighting sector electricity consumption, 125.67 kilowatt hours of electricity is saved. This energy is converted to primary energy for a more precise consumption comparison. The results indicated that Primary energy consumption decreased by 473.43 kilowatt hours or 38.4%.

7.Model validation:

In this section of the paper, an attempt is made to compare the findings of this research with the results of the studies previously mentioned. The outcomes of this study indicate that the design of a central courtyard, assuming continuous use of the north and south facades, will lead to a 23-34% reduction in primary energy consumption. On the other hand, by comparing the annual energy consumption of a typical residence (designing 60% of the site) with the total annual energy consumption of two seasonal residences (summer and winter dwellings), it has been determined that the latter scenario will result in an annual energy saving of 471.43 kilowatt-hours. This leads to a 38.4% reduction in primary energy consumption. By utilizing a migration pattern between spaces and seasonal use of these areas, energy consumption can be reduced by 4 to 15%. Table five illustrates the comparison of the results of other studies.

Table 5. Comparing the results of related researchs with the results of this research

Research results	Ref
Eslami et al. stated in their research that the use of indigenous housing patterns in hot and dry climates significantly contributes to enhancing the thermal comfort of building occupants. This study also endeavored to employ the pattern of central courtyards and migratory dwelling as indigenous models of the Kashan region to improve thermal comfort and reduce energy consumption. The results of this study, like the aforementioned research, confirm that the use of indigenous patterns can have a substantial impact on energy conservation.	[8]
According to the research by Gholinejad et al., the use of passive strategies significantly impacts energy consumption reduction. For sustainable design, climatic conditions and regional priorities established in Iran should be considered as decision-making and operational criteria. In this research, with an understanding of sustainable design patterns and recognizing the importance of referring to the ecosystem and the context of each region, an effort has been made to examine the impact of these patterns in comparison with related common patterns by referring to the indigenous architecture of Iran. The findings of this study further corroborate the influence of indigenous patterns in a more detailed continuation of previous research.	[10]
Zamani et al. have asserted in their research that design features of a courtyard, such as proportion, orientation, geometry, opening characteristics, and its materials and elements like shading devices, vegetation cover, and water bodies, significantly impact energy consumption, internal and external temperatures, solar radiation, and natural ventilation in various climates. This study further substantiates the influence of design attributes on energy consumption by examining the effect of plan arrangement and the location of the living space in two distinct plan models. Continuing the findings of their previous research, it elucidates how the juxtaposition of different components in plan design can have a substantial impact on energy consumption and the efficiency of natural ventilation.	[11]
Tahbaz et al. suggest in their research that utilizing lessons from traditional architecture, and designing in harmony with natural forces, contribute to enhancing living spaces. Their study, similar to the present research, has explored and evaluated the indigenous architectural patterns of the city of Kashan. In this research, through simulation and comparison, an attempt has been made to articulate this bioclimatic influence and the significance of alignment with local ecosystems and patterns in a more quantifiable and precise manner.	[16]
Heidari et al. endorse the concept of a deep courtyard as the most suitable building	[17]

configuration for desert environments, and they recognize small courtyards as superior thermal modulators. While this study does not investigate the proportions or depth of the courtyard, it does examine its position within the plan. This research explores the impact of a central courtyard in reducing energy consumption in hot and dry climates, demonstrating its influence on energy consumption through modeling.	
Behbood et al. propose in their research that the use of various design patterns across micro, meso, and macro scales can aid in energy consumption control and the achievement of sustainability objectives. This study, focusing on the micro scale, investigates the influence of seasonal migration and central courtyard patterns in comparison with prevalent design models. While affirming the impact of these patterns on reducing energy consumption and achieving sustainability goals, it seeks to apply an example of indigenous architectural patterns to modern living and architecture.	[22]

8. Conclusion

Energy conservation has become increasingly important due to the depletion of nonrenewable resources, population increase, and general urbanization. Researchers in the construction industry are currently working to reduce the energy consumption of buildings by combining active and passive methods. Computers and related software enable us to select the most appropriate method from among the existing ones by analyzing and carefully examining the component and geographical features of the target area and using design methods to optimize the energy efficiency of the building. Based on the available resources, using passive solutions in the design and study of local solutions in the physical structure of traditional buildings and optimizing energy efficiency are recommended. In brief, these solutions include climatic orientation, utilization of historical and indigenous examples of the region, and incorporation of the indigenous way of life. Design Builder software was employed in this study to evaluate the proposed designs and determine the efficacy of the solutions employed. Moreover, the effects of the form's design and using the spaces seasonally in accordance with the native architecture of the hot and dry region were investigated.

Additionally, the amount of savings generated by these methods should be evaluated. The analysis determined that designing the central courtyard instead of 60% of the design site, assuming continued use of the north front and south front between 23 and 34%, will reduce the demand for primary energy. The average annual energy consumption of a typical living room (60% of the site design) was compared to the total annual energy consumption of two living rooms in summer and winter. The consumption of electricity is reduced by 471.43 kilowatt hours in the second case, thus reducing primary energy consumption by 38.4%. Furthermore, it is possible to reduce energy consumption by 4-15% by using the pattern of moving between spaces and using them seasonally. Future research may focus on evaluating and analyzing the arrangement and use of all indoor spaces and uses within residential buildings, such as rooms and kitchens.

References

1. Himeur, Y., et al., Artificial intelligence based anomaly detection of energy consumption in buildings: A review, current trends and new perspectives. Applied Energy, 2021. **287**: p. 116601.
2. Markarian, E. and F. Fazelpour, Multi-objective optimization of energy performance of a building considering different configurations and types of PCM. Solar Energy, 2019. **191**: p. 481-496.
3. Kasmaee, M., climate and architecture. 1984: Iran House Building Company.
4. Razjouyan, M., Comfort through climate-compatible architecture. 1998: Shahid Beheshti University.
5. Ghobadian, V. and M. Feyz Mahdavi, Climate Design: Theoretical and Practical Principles of Energy Use in Buildings. 1989: University of Tehran.
6. saleigeh, M., Modelling of Housing Construction in Accordance with Climatic Factors of Chabahar. Geography and Development, 2004. **2**(4): p. 147-170.
7. Tavousi, T., H. Ataei, and A. Kazemi, Climate and Architectural Plan of New Constructed Schools in Isfahan. Geography and Development, 2008. **6**(11): p. 97-114.

8. Eslami Mahmoodabadi, S., S. Mofidi Shemirani, and F. Habib, Investigating the Principles of Indigenous Housing Architecture of Hot and Dry Climate of Iran with the Formal Impact Approach of the Building in Promoting Thermal Comfort of Building Users. Islamic Art Studies, 2021. **17**(40): p. 21-39.
9. Hassangholinejad Yassori, K. and S. Mofidi Shemirani, Comparative study of texts related to sustainability standards in hot and dry climate. Islamic Art Studies, 2019. **15**(33): p. 44-69.
10. gholinejad, M., et al., Analysis and upgrade resilience of coastal cities against the risk of climate change (case study: Babolsar city). Researches in Earth Sciences, 2022. **13**(1): p. 117-134.
11. Zamani, Z., S. Heidari, and P. Hanachi, Reviewing the thermal and microclimatic function of courtyards. Renewable and Sustainable Energy Reviews, 2018. **93**(1): p. 580-595.
12. Taghizade, K. and M. Mollazade Yazdani, The Impacts of Climatic (Seasonality) Strategies on Human Health in Traditional Medicine, and on the Spatial Organization of Traditional Residential Architecture. Journal of Iranian Architecture Studies, 2018. **7**(14): p. 97-123.
13. Rasti, S., Z. Mir Abdoal-Azimzadeh Mirmbini, and M. Roshan, Improving Energy Consumption in Façade Building in temperate climate., in International Conference on Architecture. 2015: Tehran.
14. Al-Yasiri, Q. and M. Szabó, Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis. Journal of Building engineering, 2021. **36**: p. 102122.
15. Geng, Y., et al., A review of operating performance in green buildings: Energy use, indoor environmental quality and occupant satisfaction. Energy and Buildings, 2019. **183**: p. 500-514.
16. Tahbaz, M., S. Djalilian, and F. Moosavi, Lessons from climatic architecture of the passages of Kashan, A field study in the traditional part of the city. Journal of Iranian Architecture Studies, 2022. **1**(1): p. 59-83.
17. Heidari, S., A deep courtyard as the best building form for desert climatean introduction to effects of air movement (Case study: Yazd). Desert, 2010. **15**(1): p. 19-26.
18. Heidari, S., A. Pitts, and S. Sharples. Adaptive comfort behaviour in Iranian courtyard houses. in World Renewable Energy Congress VI. 2000. Elsevier.
19. Zafar, M.W., et al., How renewable energy consumption contribute to environmental quality? The role of education in OECD countries. Journal of Cleaner Production, 2020. **268**: p. 122149.
20. Danesh, S.V., The role of building materials in reducing energy consumption and its impact on sustainable architecture. Payashehr Monthly, 2017. **1**(9).
21. Tafreshi, F. and B. Alemi, Energy-efficient design of building facade, inspired by human skin. Proceedings of the Institution of Civil Engineers-Energy, 2023. **176**(2): p. 105-119.
22. Behbood, K.T., M. Taleghani, and S. Heidari, Energy efficient architectural design strategies in hot-dry area of Iran: Kashan. Emirates Journal for Engineering Research, 2010. **15**(2): p. 85-91.
23. Amiri-Kordestani, M., Natural air conditioning, traditions and trends: high performance of sustainable indoor ventilation in a hot and dry climate. 2014.
24. Office, E.a.E.M.P., Deputy Minister of Electricity and Energy. 2014.
25. Alemi, B. and F. Tafreshi, Studying the importance of thermal control of walls and transparent walls in hot and dry climate of Kashan. Journal of Urban Management and Energy Sustainability, 2023. **5**(1): p. 92-103.
26. Pileh-Dar-Boni, R.-z., S. Heidari, and H. Soltan-zadeh, Behavioral Adaptation in Villas and Apartments of Rasht during Summer. Journal of Iranian Architecture Studies, 2022. **11**(21): p. 131-157.
27. Nakhai Niazi, A. and M. Gholamreza, Heating Engineering (A collection of general information on heating). first ed. 2008, Tehran: Farhang Roz.
28. Reference, E.M.A., Reference applicable to energy management, Sharif University of Technology Studies Center, Oil and Energy Department, in collaboration with Fanavaran Energy Efficiency Development Company. 2013, Sharif University of

Technology, Technology Studies Center: Tehran.
29. Duscha, M., Energiemanagement für öffentliche Gebäude: Organisation, Umsetzung und Finanzierung. 1996: Zareh Publishing.
30. Sonderegger, R., Thermal modeling of buildings as a design tool. Proceedings of CHMA, 1985. **1**: p. 53.
31. Souhankar, A., A. Mortezaee, and R. Hafezi, Potentials for energy-saving and efficiency capacities in Iran: An interpretive structural model to prioritize future national policies. Energy, 2023. **262**: p. 125500.
32. Watson, D., Climatatic design: Energy efficient building principles and practices. 1983.
33. Pakzad, J., Phenomenology of Residential Building Façade and the Evolution Process of its Expectations. Journal Honar-Ha-Ye-Ziba, 2003. **14**(14): p. 51-62.
34. Gorji, Y., et al., Assessment of climatic architecture of houses in Kashan. Armanshahr Architecture & Urban Development, 2012. **4**(7): p. 31-40.
35. Hafezi, M.R., Z. Zomorodian, and M. Tahsildoost, Energy Efficient Design of Double Skin FaÃ § ade, Case Study: an Office Building in Tehran. Journal of Iranian Architecture Studies, 2022. **5**(10): p. 101-122.
36. Gu, L. Airflow network modeling in EnergyPlus. in Building Simulation. 2007.
37. Meteorology, D.o.W.a., Climatic analysis of Kashan. 2020.
38. Office, N.B.R.C.a.P., 19th Topic of National Building Regulations for Energy Saving. 2013, Ministry of Housing and Urban Development, Vice-Chancellor of Engineering and Building Implementation System: Tehran.