JOURNAL
of DESIGN
THINKING

Energy Sustainability in Iranian Tourism Buildings: The Role of Form and Orientation in Optimizing Solar Energy Absorption and Energy Consumption

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DOI: 10.22059/jdt.2026.410809.1185

Received: *8 February 2026,* ***Revised:*** *13 June 2026,* ***Accepted:*** *14 June 2026,* ***Available Online*** *from 14 June 2026.*

Abstract

Given the increasing demand for energy and the irreversible effects of climate change worldwide, attention to energy optimization in buildings has been greater than ever before. This study examines the impact of building form and orientation on energy consumption and solar energy absorption in tourism complexes in four distinct climates of Iran cold and dry, warm and dry, temperate and humid, and warm and moist). Using Grasshopper extensions with Honeybee and Ladybug, seven different building forms were simulated from 45 ° west to 45 ° east, resulting in a total of 315 scenarios. The results show that compact forms, such as cubic and L-shaped forms, generally consume 15% to 25% less energy compared to courtyard, U-shaped, or cruciform buildings. In the cold climate of Shahrekord, the difference between forms was less visible, while in Yazd, Gorgan, and Qeshm, energy consumption varied greatly due to the higher demand for building cooling. The shape and rotation of the structure were more important in adverse climates, with some forms increasing energy consumption by 30% to 40%. In general, a cubic form with an eastward rotation (2 to 10 degrees) provides the most optimal energy efficiency and solar gain. The results show that designers' decisions about these factors early in the design process can significantly reduce the building's annual energy consumption and ultimately carbon footprint over the life of the building.

Keywords

Optimal Form, Building Orientation, Energy Consumption, Solar Energy, Tourism Complex.

Introduction

Global warming is accelerating. Since the Industrial Revolution, human activities have led to the release of greenhouse gases, contributing to an increase in the greenhouse effect. This, in turn, is causing a rise in the planet's temperature and ultimately leading to changes in ecosystems worldwide (Yang et al, 2025). This is important to note, given the energy consumption in buildings and their contribution to greenhouse gas emissions worldwide (Zhong et al. 2021). Buildings account for over 40% of the world's total energy consumption, nearly 70% of electricity consumption. Furthermore, previous research suggests that construction operations are responsible for 30% of global greenhouse gas emissions (Balali & Yunusa-Kaltungo, 2025). Optimizing the form and orientation of a building from the early design stages is a cost-effective way to achieve high energy efficiency and reduce energy costs (Rashid et al, 2017). This study places special emphasis on analyzing solar energy absorption in various building formats, which plays an important role in optimizing energy consumption.

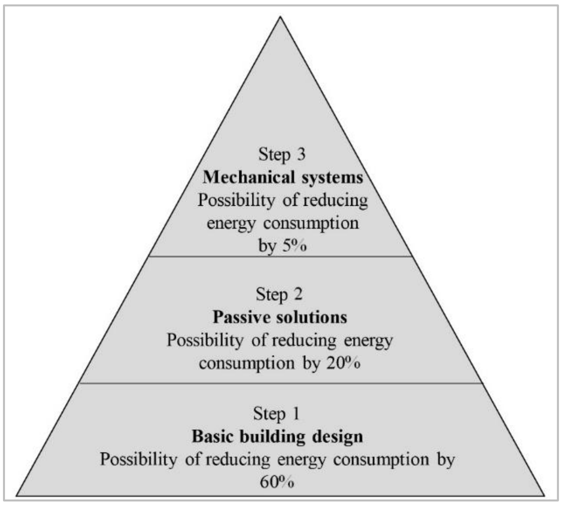


Figure 1: *Norbert Lechner's 3-Tier approach for building sustainability outlines: 3 levels of sustainable building measures.*

Figure 1 illustrates Norbert Leschner's approach to building sustainability, which includes three levels of building sustainability measures: Stage 1 - Initial building design, the most fundamental level. Making the right decisions in the early stages of building design can lead to energy savings of up to 60%, including proper building orientation, insulation, materials, and windows. Totally, these stages can reduce building energy consumption by up to 85%. It should be noted that the greatest savings occur in the first stage of design (Lechner, 2008). The form and orientation of a building are crucial for optimizing energy consumption, as they influence solar heat absorption and make early design decisions essential for energy efficiency. Tourism is currently the third-largest industry in the world, after the oil and automotive sectors (Highlights, 2023). This plays a vital role in economic development, job creation, and cultural exchange globally (Gössling, 2004). Given its rapid growth, tourism is expected to soon become the world's leading industry (Sharifabadi & Ardakani, 2014). Iran, rich in natural wonders and cultural sites, is among the top ten global destinations for tourism and ecotourism, despite its relatively slow tourism industry growth, typical of many developing countries (Bijami & Ahmad, 2019). However, it accounts for a very small share of global tourism revenue – approximately 0.01 percent (Zolfaghari, 2025); therefore, Iran's tourism potential remains largely untapped (Khodadadi, 2016). Today, countries around the world are competing to capitalize on the benefits of the tourism industry, aiming to increase their income in this sector and create diverse job opportunities. For Iran, paying attention to investment in the tourism sector is essential for having a more sustainable economy (Aleksandr et al., 2020). Iran, with its four distinct climates and diverse tourist attractions, is essential to emphasize energy consumption in tourist buildings, as these buildings are major energy consumers.

Figure 2 presents the average energy use intensity (EUI) for six different building types worldwide. Hotels are the second largest energy consumers after hospitals, mainly due to their constant activity and extensive heating, cooling, and lighting systems, making energy efficiency in these buildings of particular importance. The tourism sector as a whole account for approximately 8% of global greenhouse gas emissions, a significant portion of which comes from accommodation facilities (Gössling, 2004). With the growth of tourism infrastructure, energy consumption in tourism buildings is increasing (Khademvatani, 1392; Ebadollahi, 2023). It is currently estimated to account for between 6% and 10% of the building sector's energy consumption (Khademvatani, 1392). This highlights the urgent need for targeted energy efficiency measures in tourism-related buildings to support sustainable growth (Ahmadi & Khoshgard, 2025).

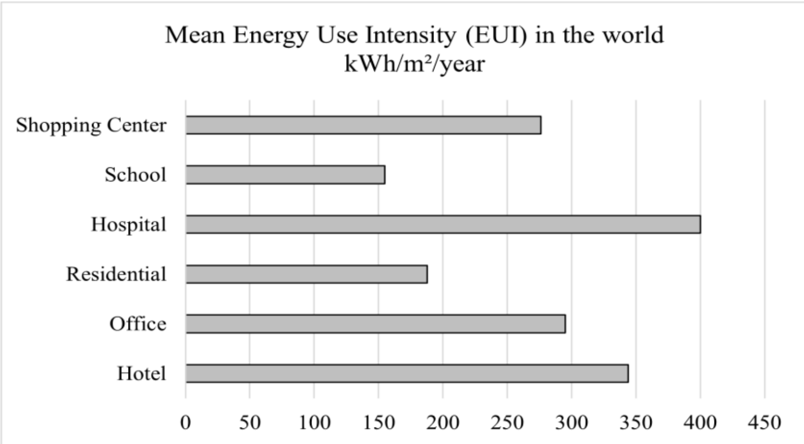


Figure 2: *Mean energy use intensity (EUI) by building type worldwide.* (Arenhart et al. 2024).

This study chose a scenario-based approach instead of genetic algorithms for building optimization, which allows designers to obtain initial results and effectively guide early design decisions quickly (Carroll, 2003). This approach is particularly valuable in the fields of construction and architecture. Scenario-based methods help architects and engineers predict the future in light of environmental changes, enabling them to achieve sustainable and energy-efficient design (O Donnell et al., 2013). Furthermore, by providing a clear framework for assessing risks and opportunities, they improve strategic decision-making and lead to stronger and more informed planning (Linden et al., 2019). Scenario modeling also facilitates evaluation by integrating various factors, such as environmental factors and energy, thereby bridging the gap between predicted and actual results (Hu et al., 2019).

The study selected four Iranian cities, Shahrekord (cold and dry (C-D)), Yazd (hot and dry (H-D)), Gorgan (Moderate and Humid (M-H)), and Qeshm (hot and humid (H-H)), to represent distinctly different climates with significant variations in temperature and solar radiation (Deng & Burnett, 2002). This study focuses on tourism-related buildings, particularly hotels, due to their high energy consumption and relative understudy, examining the building's form and orientation as key variables. Using a scenario-based approach, this study helps designers quickly identify optimal building form and orientation for annual energy consumption and solar absorption, with research indicating that such optimization can improve solar energy absorption by up to 20%, a crucial factor in Iran's varied climates (Shorabeh et al. 2022).

Table 1 shows that previous studies on building optimization in the early stages have mainly focused on residential buildings, examining variables such as form, orientation, and coverage, and considering energy consumption as the main objective, and genetic algorithms are often used for optimization.

Table 1: *Summary of previous research on building optimization in the design phase.*

Ref.	Year	Climate Zone	Occupancy	Variables	Objective Functions	Method
(H. Gholami et al., 2025)	2025	Medium Semi-Arid, Very Cold	Social Housing	Orientation, Configuration	Thermal and Visual Comfort	Genetic Algorithm
(Mahdavinejad et al., 2024)	2024	Various	Office	Envelope	Energy Consumption, Visual Comfort	Genetic Algorithm
(Na Zhao & Jia Zhang, 2024)	2024	Cold	Office	Shape, Material	Energy Consumption, Carbon Emissions	Genetic Algorithm
(Jin Li, 2024)	2024	Various	Not Mentioned	Shape	Energy Consumption	Genetic Algorithm
(Li et al., 2024)	2024	Various	Office	Shape	Energy Performance, Daylighting	Genetic Algorithm
(Samami et al., 2024)	2024	Various	Residential	Orientation, Skylight	Energy Consumption	BIM model
(Jin Zhan & Wenjing He, 2024)	2024	Various	Residential	Envelope	Thermal comfort, Carbon Emission, Cost	Genetic Algorithm
(Vassiliades, 2024)	2024	Mediterranean	Residential	Orientation, Typology	Energy Consumption	Scenario Base
(Ke Liu et al., 2023)	2023	Hot and cold	Residential Block	Shape	Energy Consumption, Daylighting	Genetic Algorithm
(Emad Elbeltagi, 2023)	2023	Desert	Residential	Envelope	Energy Consumption, Thermal Comfort	Genetic Algorithm
(Longwei Zhang & Chao Wang, 2021)	2021	Cold	Exhibition Hall	Shape	Energy Efficiency	Genetic Algorithm
(Akbaria, 2020)	2020	Hot-dry	Not Mentioned	Shape, Orientation	Energy, Radiation	Theoretical Calculations
(Halwatura et al., 2019)	2019	Tropical	House	Shape, Orientation, WWR	Energy for lighting, Thermal Comfort	Theoretical Calculations
(Jin, 2019)	2019	Cold	Rural Houses	Orientation, Envelope	Energy Consumption	Scenarios Base
(Lapisa, 2019)	2019	Various	Single-Story Commercial	Shape, Orientation	Energy Consumption	TRNSYS
(Konis et al., 2016)	2016	Various	Medium Office	Shape, Orientation, Fenestration	Daylighting, Natural Ventilation	Genetic Algorithm
(Lai Wei et al., 2016)	2016	Various	Office	Shape	Energy Consumption	Machine Learning
(Mahdavinejad, 2015)	2015	Cold	Residential	Shape, Orientation, WWR	Energy Consumption	Scenario Base
(Edwin Rodríguez-Ubinasa et al., 2014)	2014	Mediterranean	Net Plus Energy Houses	Envelope	Energy efficiency	Scenario Base
(Deng & Burnett, 2002)	2012	Sub-Tropical	Hotel	HVAC Systems	Energy Consumption	Theoretical Calculations
(Yun Kyu Yi, 2009)	2009	Not-Mentioned	Not-Mentioned	Geometry Variables	Energy Consumption	Genetic Algorithm

Research aim

With designers becoming more aware of the impact of buildings on energy consumption and carbon emissions, they have been led to optimize the total energy consumption of the building (Konis et al., 2016). Optimizing building design in the early stages is critical for establishing sustainability, as it enables predictions and strategies that reduce energy consumption and greenhouse gas emissions in the building sector (Jin & Jeong, 2014). It should be noted that building optimization should be done in the early stages of design, when initial decisions are made about form, orientation, site planning, landscape design, windowing, etc. This requires less time, energy, and cost than post-construction solutions (Elbeltagi et al., 2023). Failing to optimize building shape and orientation during design leads to greater reliance on mechanical heating, cooling, and lighting systems, increasing both energy consumption and carbon footprint over the building's life cycle (Gardezi et al, 2021). This neglect also compromises the quality of the indoor environment, including natural light and air quality, reduces the potential for effective natural shading, exacerbates the adverse effects of prevailing winds, and reduces solar gain (Torabi, 2023). This paper uses a scenario-based method to optimize building form and orientation, aiming to create energy-efficient structures in four Iranian climates; this approach focuses on maximizing solar energy absorption, lowering annual energy use, reducing carbon footprint, and improving occupant comfort. As illustrated in Figure 3, this study initially focused on three main objectives: determining the optimal orientation, achieving the best building form, and developing an organic architectural design. These overall objectives were then divided into smaller and more specific objectives. In addition to reducing annual energy consumption, this study aims to maximize solar energy absorption by optimizing building form and orientation.

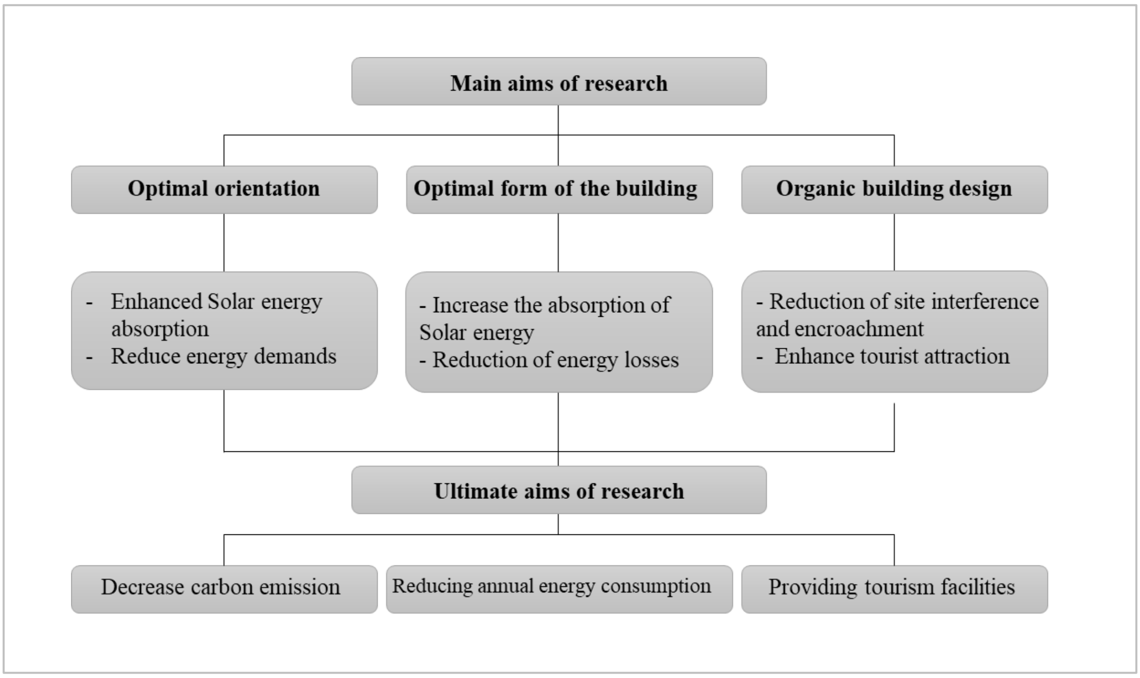


Figure 3: *Research Strategy.*

Methodology

A summary of the research is provided in Figure 4. The study investigates the optimal form and orientation of a tourist building in four diverse climate zones. The first stage addresses the existing problems, including the increasing significance of the issue at various global levels. In the second step, the data collection locations are shown on the global map. Subsequently, the next stage provides a comprehensive overview by examining the regions' climatic conditions, assessing their tourism potential, and evaluating the feasibility of solar energy production by analyzing the amount of direct sunlight in each location. The fourth step presents the simulation tools and engines utilized for this research. In the fifth step, two main variables were determined using different modeling and energy analysis tools: (1) different orientations from 45° West to 45° East, and (2) seven selected forms. In the sixth step, the software settings are briefly mentioned, and weather files, building usage, window-to-wall ratio (WWR), and other parameters are entered into the software. In this study, solar energy absorption is defined as the annual sum of direct and diffuse solar radiation (kWh/m2) on the external surfaces of the building envelope and is calculated using Ladybug radiation analysis. To measure it, the geometry of each form was modeled as a closed envelope without precise window openings to determine the geometric effect of the building shape on solar exposure. Therefore, the optical properties of materials and solar heat gain coefficient (SHGC) are not explicitly included in this measure; their effect is reflected indirectly in the EnergyPlus annual energy consumption simulations. Ultimately, the solar energy absorption index should be interpreted as a relative measure of how well different building forms absorb solar radiation at the envelope surface, rather than as an exact estimate of the net internal solar gain. As previously mentioned, the goal in all stages is to achieve the optimal form and orientation of the tourism building in the four different climatic zones of Iran, so that ultimately the most optimal form and rotation can be determined for each climatic condition. In the final step, the optimization methods were clearly defined, and data analysis software was used to compare the results.

To isolate the effect of building shape and orientation, envelope properties, WWR, glazing, heating, ventilation, and air Conditioning (HVAC) settings were held constant across all climates. This solution ensures that differences in energy outcomes are primarily due to differences in geometry and climate rather than to the specific envelope design in each climate. In practice, envelope and system specifications must be specific to each climate, and current assumptions of parameters may over- or underestimate absolute energy consumption for specific climates. However, relative comparisons between shapes are still meaningful.

In this paper, direct validation with measured data from Iranian hotels was not possible due to the lack of accurate monitoring data, and the results rely on modeling in the validated EnergyPlus engine and calibrated parameter values according to ASHRAE. However, based on the paper by Deng and Burnett (2002), which stated that the total energy consumption range in 16 hotels surveyed in Hong Kong was in the range of 297 to 936 kWh/m2/year, and in this paper, the energy consumption in different climates was in the same range, and this large-scale agreement is a health check for the model. Since the outputs are only from simulations and we do not have measured data, the model outputs depend on the accuracy of the EnergyPlus weather (EPW), thermal models, and assumptions (occupancy, schedules), and quantitative uncertainty is not provided.

1. *Methodology Framework*

The proposed framework consists of three main steps: basic information collection, modeling and energy simulation, and comparing the results of the last step. The details for each stage are elaborated in Figure 5. In the first stage, the influencing parameters were separated into two parts (location-dependent factors), such as weather data, geometry, and other factors, such as the tourism industry, occupancy, HVAC systems, and materials, and then the impact of each on the research result was determined. In the next step, all parameters were entered into the Grasshopper and Honeybee, and the results were compared. In the third step, comparison tools are used to convert the data into graphs to find the optimal form and rotations. The evaluation is carried out based on the total annual energy consumption as well as the solar radiation absorbed by each shape and orientation of the building using Honeybee and Ladybug tools, and the comparison of the results provides a more complete picture for optimization decisions. The Honeybee/Ladybug tool is based on EnergyPlus, which has been validated many times in reputable studies for hotels and similar buildings (Arenhart et al., 2024). As mentioned, due to existing limitations, direct validation with measured data from Iranian hotels was not possible.

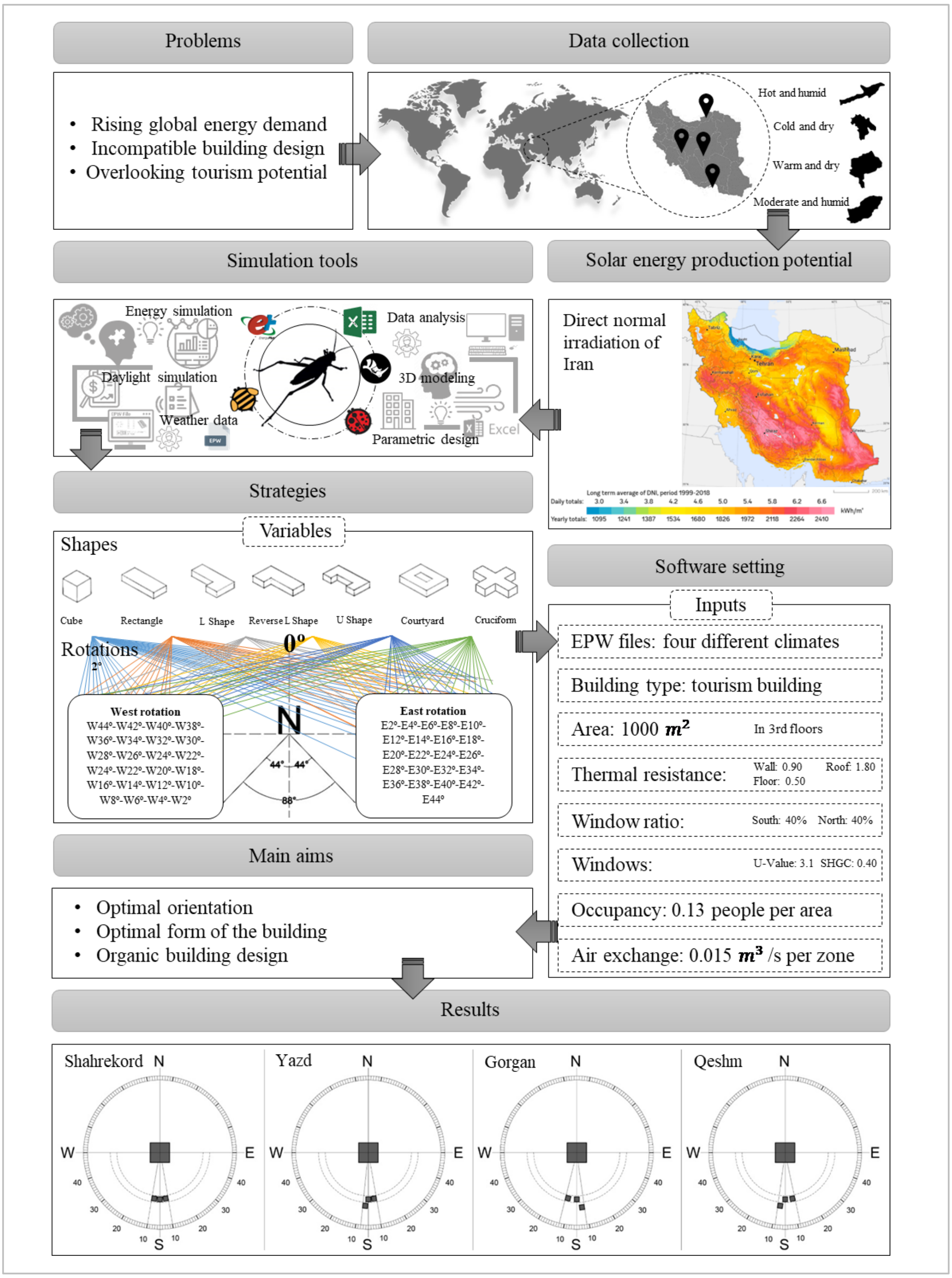


Figure 4: *Summary of the pivotal parts of the study.*

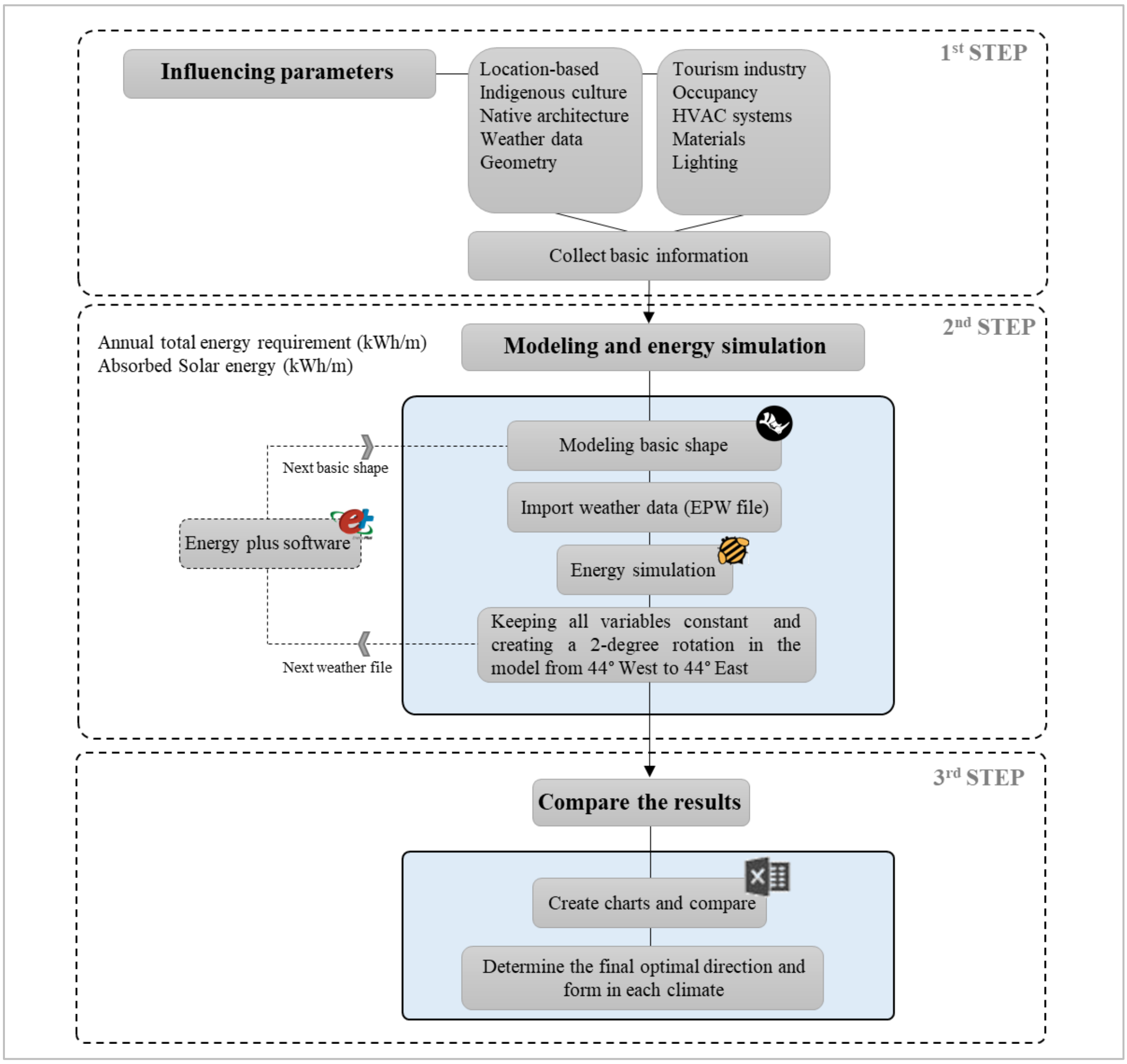


Figure 5: *Proposed workflow.*

2. *Weather data*

To better understand the selected climates, the climatic characteristics of each are explained with the help of its diagram.

Temperature

Chart 1 shows that Shahrekord has cold weather for five months of the year, and from March to October, the temperature gradually increases during the day, and the weather becomes warmer. These temperature changes in spring cause the temperature to reach above 20 ºC in the afternoons, while the hottest period is between June and August, when the temperature reaches above 30 ºC for most of the day.

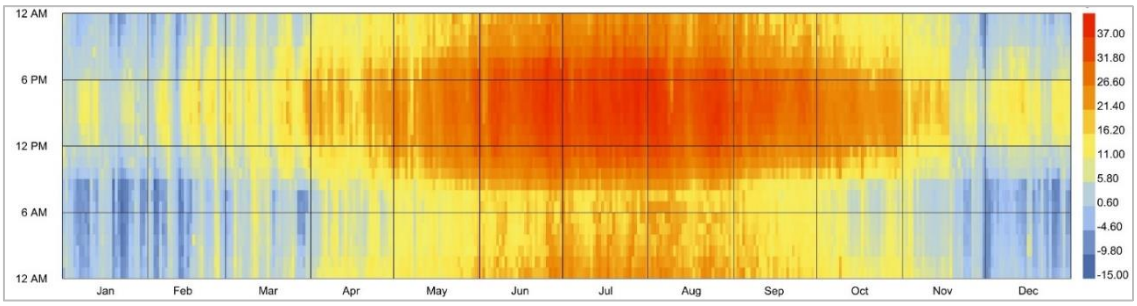


Chart 1: *Dry bulb temperature of Shahrekord, Iran, hourly temperature (ºC), from January to December, in the period of 2009-2023* (Climate.onebuilding.org, 2018).

Chart 2 displays the dry temperature of Yazd, Iran, from January to December. The temperature is at its lowest in January and December, falling below 5 ºC. However, the temperature increases sharply in spring and summer. From June to September, the midday temperature even reaches more than 43 ºC.

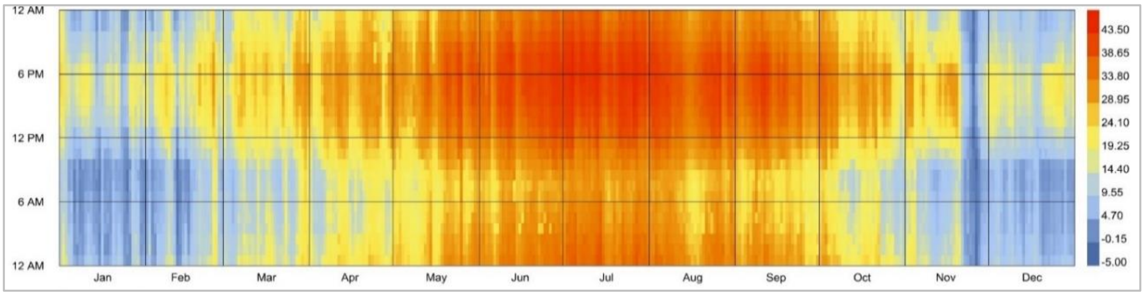


Chart 2: *Dry bulb temperature of Yazd, Iran, hourly temperature (ºC), from January to December, in the period of 2009-2023* (Climate.onebuilding.org, 2018).

Chart 3 visualizes the annual temperature of Gorgan, which in the winter months drops below 4 ºC, while in the summer the temperature increases significantly and reaches 41 ºC. The hottest hours in this city are between 12 noon and 6 pm.

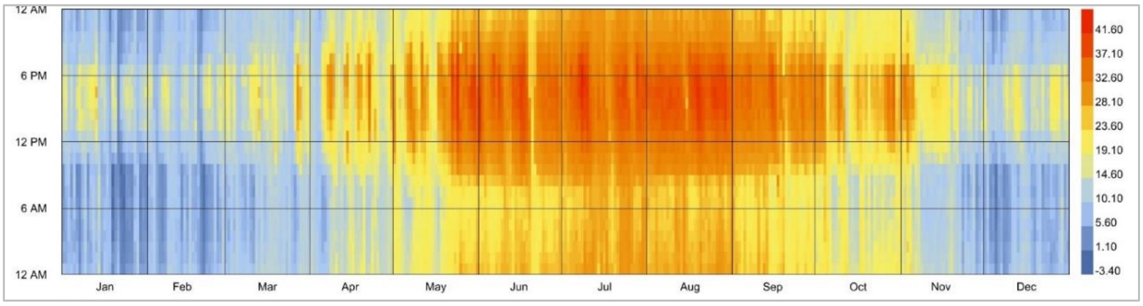


Chart 3: *Dry bulb temperature of Gorgan, Iran, hourly temperature (ºC), from January to December, in the period of 2009-2023* (Climate.onebuilding.org, 2018).

Chart 4 presents dry bulb temperature data for Qeshm, Iran, where temperatures are above 10 ºC in winter nights and mornings, and from May to September, temperatures can reach above 44 ºC in the afternoons, indicating long, hot summers in this region, but Qeshm generally has milder winters.

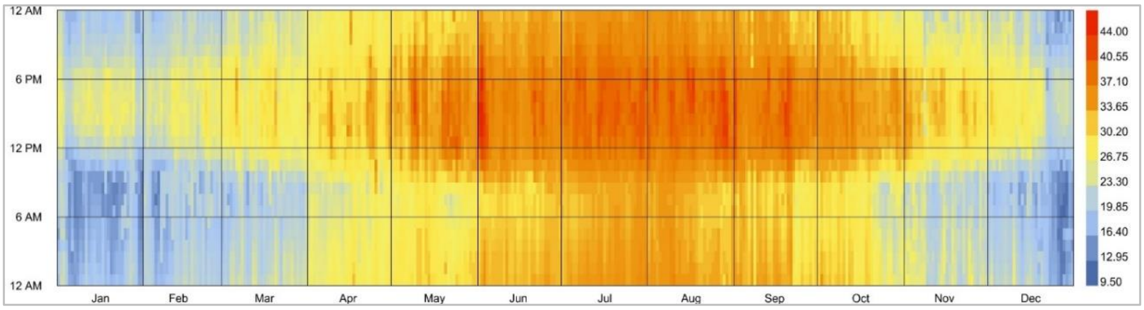


Chart 4: *Dry bulb temperature of Qeshm, Iran, hourly temperature (ºC), from January to December, in the period of 2009-2023* (Climate.onebuilding.org, 2018).

Table 2 summarizes general information about all four cities of the study, and given the extent of Iran, there is the greatest difference in latitudes. Shahrekord has the lowest temperature of -0.66 ºC, and Qeshm has the highest temperature of 34.28 ºC. Also, according to the table, Gorgan and Qeshm have the highest relative humidity compared to Shahrekord and Yazd.

Table 2: *Summary of weather data of Shahrekord, Yazd, Gorgan, and Qeshm.*

City	Latitude	Longitude	Elevation (m)	Annual Temp. (ºC)			Ave. RH (%)
				Max.	Min.	Ave.	
Shahrekord	32.2927° N	50.8396° E	2,049 m	25.05	-0.66	12.23	42.67
Yazd	31.9036° N	54.2890° E	1,235 m	34.69	7.64	20.97	25.17
Gorgan	36.9049° N	54.4131° E	-7 m	28.99	6.80	17.68	70.53
Qeshm	26.7510° N	55.8980° E	12 m	34.28	18.98	27.29	63.63

Chart 5 provides the climate data for four different cities in Iran with their climatic differences. As is clear from the charts, Shahrekord is relatively cold most of the year, with temperatures below 16 ºC, 64% of the time, and comfortable conditions prevailing only 22% of the time. In contrast, Yazd has warmer climate conditions, with temperatures above 25 ºC, 40% of the time, and relatively comfortable conditions prevailing in this city 24% of the time. On the other hand, Gorgan has a more moderate climate compared to these two cities, with temperatures below 25 ºC, 65% of the time, and finally Qeshm, where temperatures have never been recorded below 16 ºC and temperatures above 25 ºC more than 60% of the time.

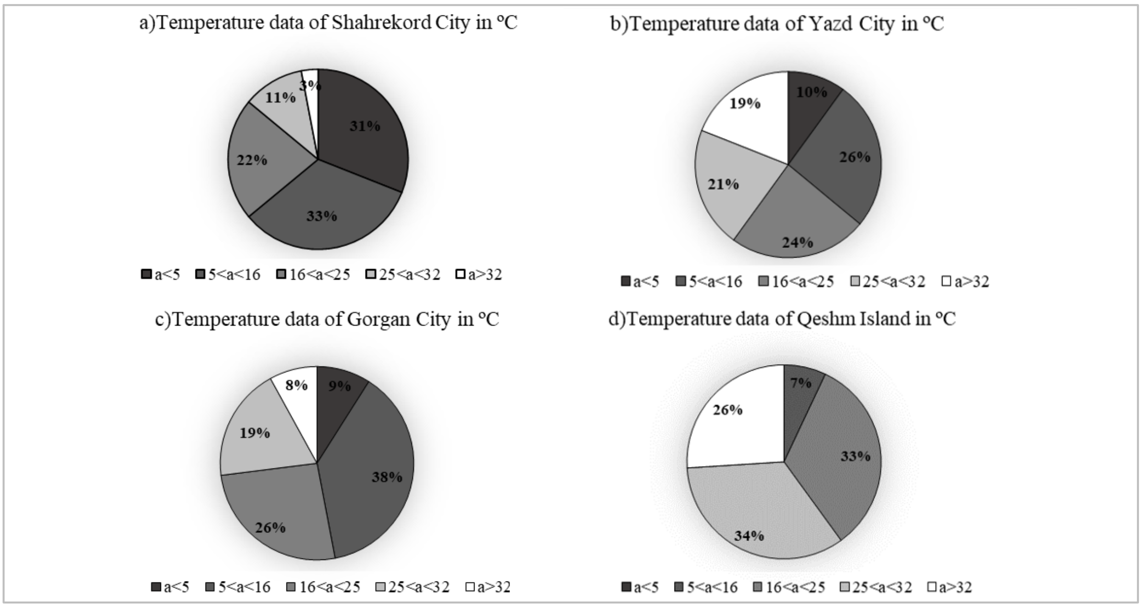


Chart 5: *Different weather conditions of four cities in the period of 2009-2023* (Climate.onebuilding.org, 2018).

Sunlight

Chart 6 shows that in all four cities, the highest solar radiation is concentrated towards the south (0º), reflecting the sun's usual path in the northern hemisphere, where Iran is located. Shahrekord and Qeshm have the highest peak values of about 73.38 kWh/m² and 72.22 kWh/m², while Yazd and Gorgan reach 71.18 kWh/m² and 59.36 kWh/m², respectively. Northern directions receive minimal radiation, typically close to zero. These findings show that southern and central regions of Iran, such as Yazd and Qeshm, have very high solar potential, with average daily values often exceeding 5.7–6.3 kWh/m² (over 2000 kWh/m² annually). This is much higher than global averages and emphasizes Iran's exceptional solar energy capacity due to its position in the sun belt.

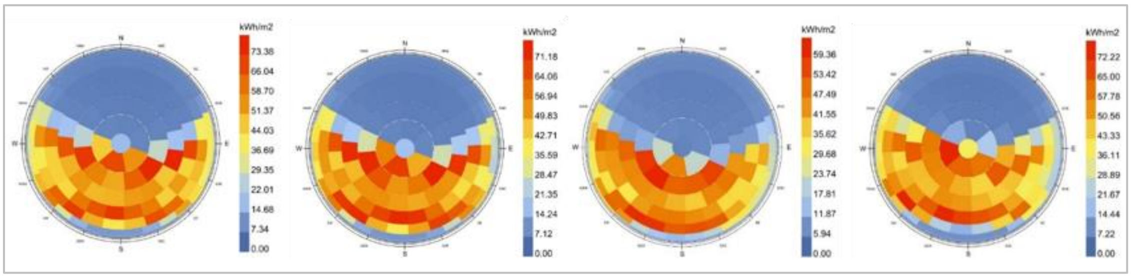


Chart 6: *Graph of the direct, diffuse, and total radiation (kWh/m^2) of Shahrekord, Yazd, Gorgan, and Qeshm* (Climate.onebuilding.org, 2018).

3. *Model description*

The need for more support for architects using environmental analysis tools in the design process has increased with an increasing focus on high-performance design. Today, many designers use Grasshopper/Rhino as one of the most widely used tools. The number of environmental plugins available for this software has grown significantly; however, Honeybee/Ladybug has received considerable attention due to its advantages (Roudsari & Pak, 2013). With Ladybug, importing EPW files into Grasshopper enables users to produce diverse two-dimensional (2D) and three-dimensional (3D) graphics that are valuable in the design process. Previous research in this field has examined commercial and office areas with intermittent uses, and appropriate forms for these uses have been described. In the present study, the same forms have been investigated in the continuous use of a tourism complex. From the wide range of available forms, seven basic forms were selected for further analysis, from compact to open, to encompass a wide range of shapes and climatic strategies: 1:1 cube as the most adaptable form to both cold and warm climate conditions (Straube, 2012), Rectangular form with a ratio of 1:2.5 due to its east-west elongation to absorb the most solar energy (Straube, 2012), L-shape to create a barrier against prevailing westerly and southwesterly winds and as a representative of more complex shapes (Stasi et al., n.d.), The central courtyard as one of the ancient climatic solutions in the cold, hot and dry climate of Iran with a height to width ratio of 1:1 (Seddik Hassan et al., 2024), The cruciform shape is a form that is suitable for temperate and humid climates due to the possibility of natural ventilation from all four sides (Stasi et al., n.d.), and finally the U form, which is a modified central courtyard (Stasi et al., n.d.), these forms were modeled using Rhino 3D software with an area (1,000 square meters based on the greater importance of this area in international standards and the importance of observing energy principles in them and the reality of tourism projects, as well as the ability to simulate energy) (Salvalai et al., 2015), and the same number of floors (three floors to accommodate 30 users simultaneously)

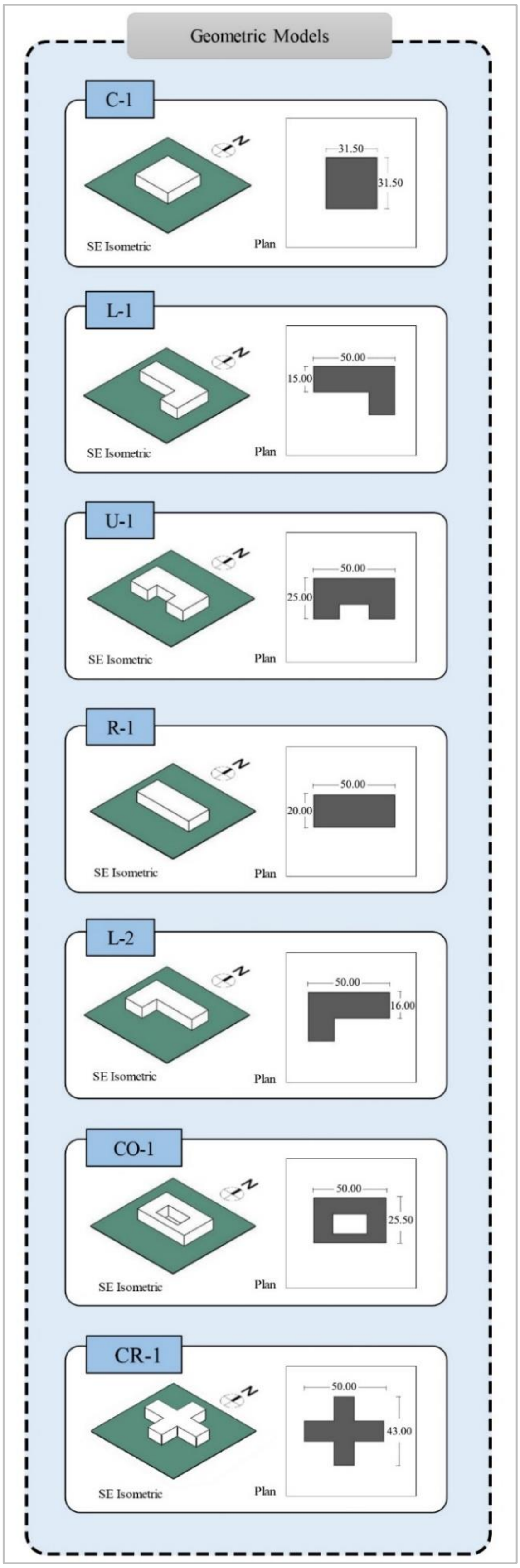


Figure 6: *Geometric models.*

(Flotation, 2022), and then imported into Grasshopper to make energy model adjustments.
As shown in Figure 6, seven basic forms with codes, C-1, L-1, U-1, R-1, L-2, CO-1, CR-1 in the same total area (3000 square meters) on three floors, with a window to the wall ratio (WWR) equal to 40%, WWR for the North and South wall (American Society of Heating, 2017), and also the thermal resistance of the external walls, roof, and floor adjacent to the soil are considered as 0.9, 1.8 and 0.5 m^2.k/W respectively (Ministry of Roads and Urban Development, 2021). According to the ASHRAE energy standard, the amount of air exchange and lighting required by users is specified, as well as the time and schedule of users' presence in the space, the level of mobility (Ministry of Roads and Urban Development, 2021), and other relevant information. It should be noted that, as is clear from the proportions and dimensions of the forms, in all forms, the southern side is considered to be the most effective side in absorbing solar energy, equal to 50 meters, so as not to disrupt the research process.
The forms were compared in terms of their compression ratio, and the results of each are listed in Table 5. The following formula was used to calculate the compression ratio:

$$Compactness\ C = \frac{Volume}{Area}$$

4. *Simulation tools*

In this study, advanced simulation tools were used to thoroughly examine how building shape and orientation affect energy performance across four distinct climates. The main software was Grasshopper, a visual programming tool that works with Rhino 3D modeling software. This setup allowed the creation of precise models of seven different building forms. Each design form was rotated 2 degrees, shifting from West to East, which created a total of 315 unique design scenarios. Honeybee and Ladybug plugins within Grasshopper were relied upon for detailed energy analysis. Ladybug helped to import climate data and create clear 2D and 3D visualizations of environmental factors like solar radiation and temperature changes. Honeybee took it further by simulating energy consumption, heating needs, and solar energy absorption based on these models. By combining these tools, complex calculations are automated, and various environmental and architectural variables are effectively managed. This process produces detailed and accurate data, including annual energy consumption and solar radiation, for each situation. These results are then analyzed using specialized software to identify the best building forms and orientations.

Simulation setup

In Grasshopper, for energy analysis with Honeybee, data was entered into the relevant components based on Table 3, the items mentioned in all forms are considered the same, such as the area of each form, the percentage of openings in each direction, the specifications of the windows, the Thermal resistance of walls, and other effective parameters such as the amount of air conditioning, the required lighting, electrical and mechanical equipment, and the hours of users' presence in the space were applied to the software and the variables were entered, such as a 2-degree rotation from west to east, the optimal rotation range in Iran, based on the reviewed articles, the range from 45 degrees east to 45 degrees west is defined as the range where the highest solar energy absorption is achieved, and accordingly, this range has been considered in this article as the rotation range of forms (Akbari & Hosseini Nezhad, 2019; Kasmae, 2003). Then, by designing an optimization algorithm, each form in these 45 rotation modes was examined. The outputs related to total annual energy consumption and the amount of solar energy absorbed were entered into data analysis software for review and analysis to provide a better graphical comparison.

Table 3: *Grasshopper parameter sets.*

Control parameters	Value	Unit
Total area	3,000	m^2
Number of floors	3	-
Window-to-wall ratio: *South* *North*	 40% 40%	-

Windows: *U-value* *SHGC*	3.10 0.40	*W/m². k* -
R-value: *Walls* *Roof* *Floor*	0.90 1.80 0.50	*m².k/W*
Air exchange	0.015	*m³/s flow per zone*
Infiltration	0.0001	*m³/s per zone*
Required light for the *living space*	7.60	*Watts per area*
Occupancy	0.13	*People per area*
Electric equipment	4	*Watts per area*
Hot water	0.27	*Flow per area*

3. *Optimization*

Optimization means finding the best architectural design (Chen & Wang, 2023). Design phase optimization is highly valuable, as it lets designers explore solution options early in a building's life cycle to select the best balance of performance, cost, and other key constraints (Manmatharasan et al., 2025). These early-stage optimizations are critical because they are more cost-effective than modifications made after construction and have the greatest impact on building performance overall (Negendahl, 2015). In building optimization studies, three main sustainability goals are usually mentioned: reducing operational energy demand, increasing daylight performance levels, and reducing carbon emissions (Manmatharasan et al., 2025). Occupant comfort and economic costs are also considered performance objectives (Jin Zhan & Wenjing He, 2024). This article prioritizes reducing annual energy consumption by optimizing building form and orientation, emphasizing the exploration of different spatial layouts and placements early in the design process. As shown in Table 6, two variables of optimal form and building orientation are stated as influential factors in the early stages of design, and the overall goals of reducing annual energy consumption and the amount of absorbed solar energy, which have been proposed as basic goals since the beginning of the research, have been examined. Scientific studies use a variety of methods for building optimization, including genetic algorithms, multi-objective optimization, particle swarm optimization, machine learning techniques, and simulation tools based on building information modeling (BIM) (Choi et al, 2024; Rong et al., 2025). Genetic algorithms are the most popular multi-objective optimization method. Machine learning algorithms have also attracted increasing attention due to their ability to accurately predict building performance (Wu et al., n.d.; Kubwimana & Najafi, 2023). However, in this study, this approach was used due to the unique advantages of the scenario writing method (Brucke et al., 2020). The scenario writing method possesses several key capabilities, including the ability to provide rapid initial results in the early stages of design, the capacity to evaluate multiple possible futures, simplicity in implementation and interpretation of results, and the ability to fully control variables (Brucke et al., 2020; Kubwimana & Najafi, 2023). It also provides a structured framework for assessing risks and opportunities, leading to stronger and more informed planning (Canbolat & Albak, 2024). In addition, scenario modeling allows for a comprehensive assessment of building performance by integrating environmental, energy, and operational factors (Altun, 2015). Since the number of states examined in this study was small, this method was used to measure all states, and all possible states were examined one by one based on the variables.

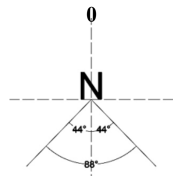
Table 4: *Variables and objective functions of the research.*

Variables	Objective functions
Building orientation Building shape	Reducing annual energy consumption Enhanced solar energy absorption

Results

This study aimed to determine the optimal form and orientation for a tourism complex in four different climates. To achieve this goal, seven main building forms were analyzed at 45 rotation angles (from 45° West to 45° East) for a total of 315 unique design scenarios. Simulations were performed using Grasshopper with the Honeybee and Ladybug extensions, evaluating the total annual energy consumption and solar radiation for the different design scenarios. Since the difference in data in rotations was very small, the following graphs are adjusted based on a difference of 4 rotations. The findings are elaborated below, and detailed comparisons are presented in Table 5.

Table 5: *Final results of total energy consumption for the seven selected shapes.*

Model *ID*	C-1	R-1	L-1	L-2	U-1	CO-1	CR-1
Shape names	Cube	Rectangle	L	Reverse L	U	Court yard	Cruciform
Model proportions	1:1	1:2.5	1:3	1:3	1:2	1:2	1:1.5
Shape Compactness	2.98	2.87	2.74	2.74	2.23	2.15	2.51
Area	3000m²	3000m²	3000m²	3000m²	3000m²	3000m²	3000m²
Number of floors	3	3	3	3	3	3	3
Model rotations	W44º-W42º-W40º W38º-W36º-W34º W32º-W30º-W28º W26º-W24º-W22º W24º-W22º-W20º W18º-W16º-W14º W12º-W10º-W8º W6º-W4º-W2º					E2º-E4º-E6º-E8º E10º-E12º-E14º E16º-E18º-E20º E22º-E24º-E26º E28º-E30º-E32º E34º-E36º-E38º E40º-E42º-E44º	
Average annual energy consumption in Shahrekord (*C-D*)	262.81 kWh/m²	264.11 kWh/m²	266.30 kWh/m²	266.29 kWh/m²	265.39 kWh/m²	276.32 kWh/m²	269.38 kWh/m²
Average annual energy consumption in Yazd (*H-D*)	290.47 kWh/m²	291.67 kWh/m²	293.48 kWh/m²	293.36 kWh/m²	291.94 kWh/m²	301.64 kWh/m²	295.65 kWh/m²
Average annual energy consumption in Gorgan (*M-D*)	299.96 kWh/m²	300.85 kWh/m²	302.30 kWh/m²	302.24 kWh/m²	300.86 kWh/m²	309.41 kWh/m²	303.98 kWh/m²
Average annual energy consumption in Qeshm (*H-H*)	447.92 kWh/m²	449.25 kWh/m²	450.99 kWh/m²	450.79 kWh/m²	448.12 kWh/m²	461.93 kWh/m²	453.14 kWh/m²

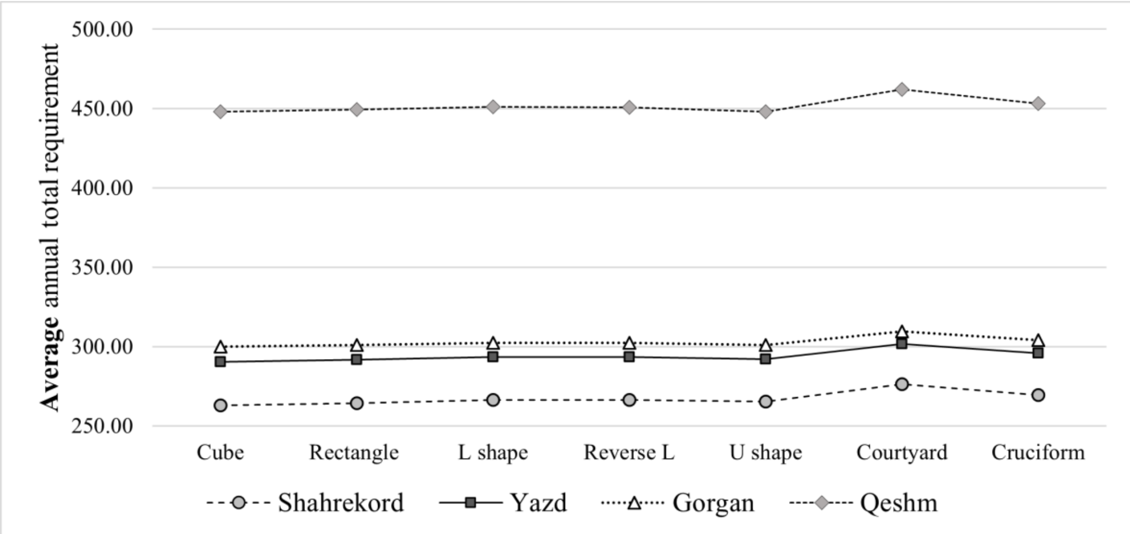


Chart 7: *Average energy consumption of selected forms for different climate zones.*

Chart 7 compares that compact building forms (cubes, rectangles, Ls, inverted Ls) have the lowest energy use (around 252 kWh/m² in Shahrekord, 450 kWh/m² in Qeshm), while more complex forms (U-shaped, courtyard, cruciform) require 10–20% more energy; using compact forms can reduce energy needs by 15–25%, especially in colder climates like Shahrekord.

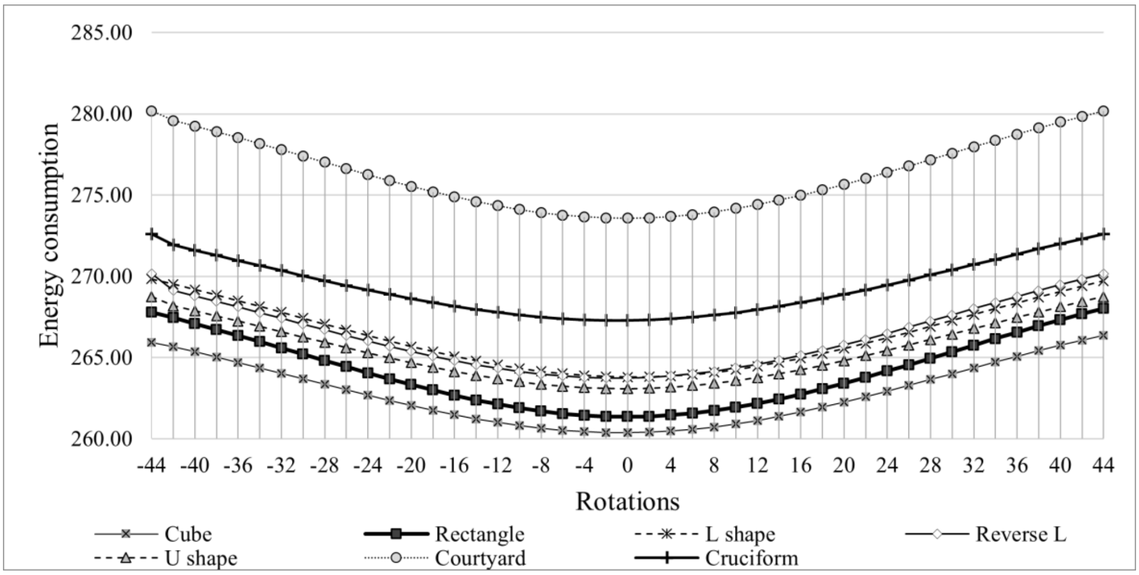


Chart 8: *Energy consumption of selected forms for Shahrekord.*

Chart 8 shows energy use for different building forms and rotations in Shahrekord: cubic shapes have the lowest consumption at about 260 kWh/m² with rotations between 0 and -20 degrees, while rectangles and U-shapes are optimal at negative rotations with 261–269 kWh/m². L-shaped, central courtyard, and cross forms have higher consumption (above 280 kWh/m²) due to larger external surfaces exposed to cold winds. Generally, negative rotations (from -44 to 0 degrees) reduce energy use, with best performance between 0 and -20 degrees; positive rotations increase energy requirements due to less solar gain and more cold wind exposure. Complex shapes are less efficient compared to compact forms.

Table 6: *Regression prediction equation for energy consumption for selected forms in Shahrekord.*

Shapes	Regression Equation	R^2 Value
Cube	$y = 0.0031x^2 + 0.0051x + 260.72$	$R^2 = 0.9801$
Rectangle	$y = 0.0035x^2 + 0.0027x + 261.74$	$R^2 = 0.9802$
L-shape	$y = 0.0032x^2 - 0.0022x + 264.14$	$R^2 = 0.9816$
Reverse L-shape	$y = 0.0033x^2 + 0.0081x + 264.06$	$R^2 = 0.9842$
U-shape	$y = 0.003x^2 + 0.0027x + 263.38$	$R^2 = 0.9843$
Courtyard	$y = 0.0035x^2 + 0.0026x + 273.97$	$R^2 = 0.9802$
Cruciform	$y = 0.0028x^2 + 0.0049x + 267.51$	$R^2 = 0.9888$

Table 6 demonstrates that energy consumption for different building shapes is strongly predicted by quadratic equations based on rotation angle $y=ax2+bx+cy=ax2+bx+c$, with high accuracy (R^2>0.98 R^2>0.98) across all models. Compact forms like cubes and U-shapes have lower baseline consumption values (~260.72 for cubes) compared to more complex layouts (~273.97 for courtyards). The quadratic term ($a \approx 0.003$) shows consumption rises as rotation moves away from the optimal angle, and the linear term (b) provides a minor adjustment depending on rotation direction. These findings highlight both the significance of shape and the impact of precise orientation on building energy use.

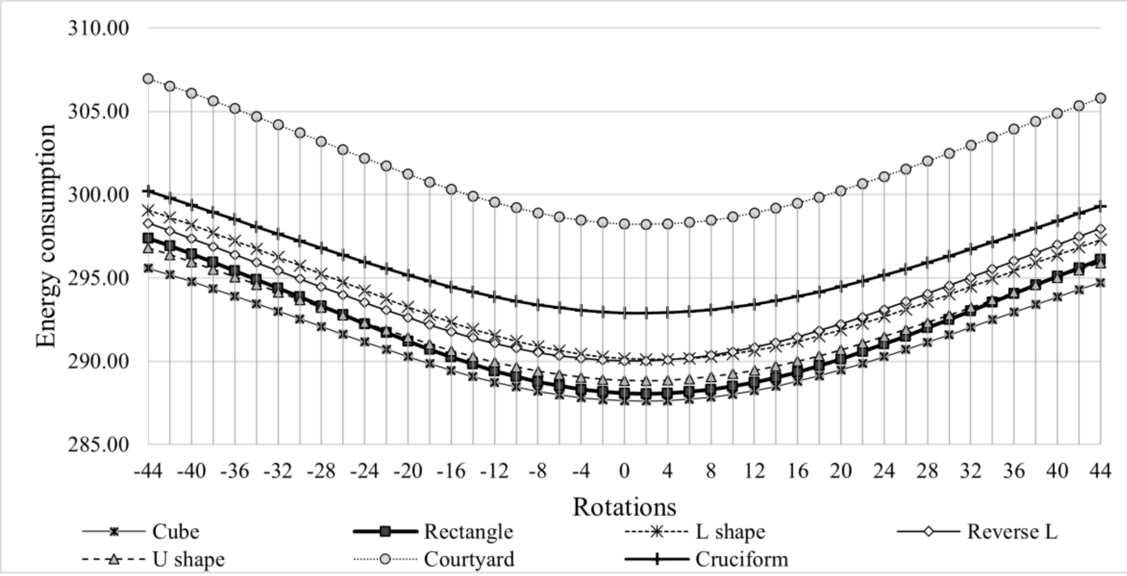


Chart 9: *Energy consumption of selected forms for Yazd.*

Chart 9 reveals that in Yazd's hot, dry climate, cubic building shapes offer the lowest and most stable energy consumption (288–295 kWh/m²). Rectangles, L, inverted L, and U forms have moderate to high energy use, showing the highest efficiency at 0° rotation, which reduces direct sunlight and cooling needs. The courtyard consumes the most energy overall due to extensive surface exposure, and extreme rotations greatly increase energy use by exposing more facade to the sun; thus, exact orientation is especially important for minimizing energy use in hot, dry climates.

Table 7: *Regression prediction equation for energy consumption for selected forms in Yazd.*

Shapes	Regression Equation	R^2 Value
Cube	$y = 0.004x^2 - 0.0142x + 288.02$	$R^2 = 0.9819$
Rectangle	$y = 0.0046x^2 - 0.02x + 288.54$	$R^2 = 0.9822$
L-shape	$y = 0.0043x^2 - 0.0264x + 290.59$	$R^2 = 0.9817$
Reverse L-shape	$y = 0.0043x^2 - 0.006x + 290.44$	$R^2 = 0.9839$
U-shape	$y = 0.004x^2 - 0.0138x + 289.23$	$R^2 = 0.9837$
Courtyard	$y = 0.0044x^2 - 0.0182x + 298.71$	$R^2 = 0.9801$
Cruciform	$y = 0.0036x^2 - 0.0136x + 293.19$	$R^2 = 0.9887$

Table 7 presents quadratic models relating building rotation angle (x) to energy consumption (y) for various building shapes, with R^2 values all above 0.98 indicating high model accuracy. The constant terms represent the baseline energy consumption at zero rotation, with the lowest value for the cube (288.02) and the highest value for the courtyard (298.71). The x^2 coefficients range from about 0.0036 to 0.0046, indicating that energy consumption increases quadratically as the building deviates from the optimal orientation. The negative linear coefficients indicate an initial decrease in energy consumption with increasing rotation, before the quadratic effect becomes dominant. In general, compact shapes such as cubes and U-shapes have lower baseline consumption, while more complex shapes such as courtyards and cruciform forms consume more energy, but the angle of rotation significantly affects energy efficiency for all shapes.

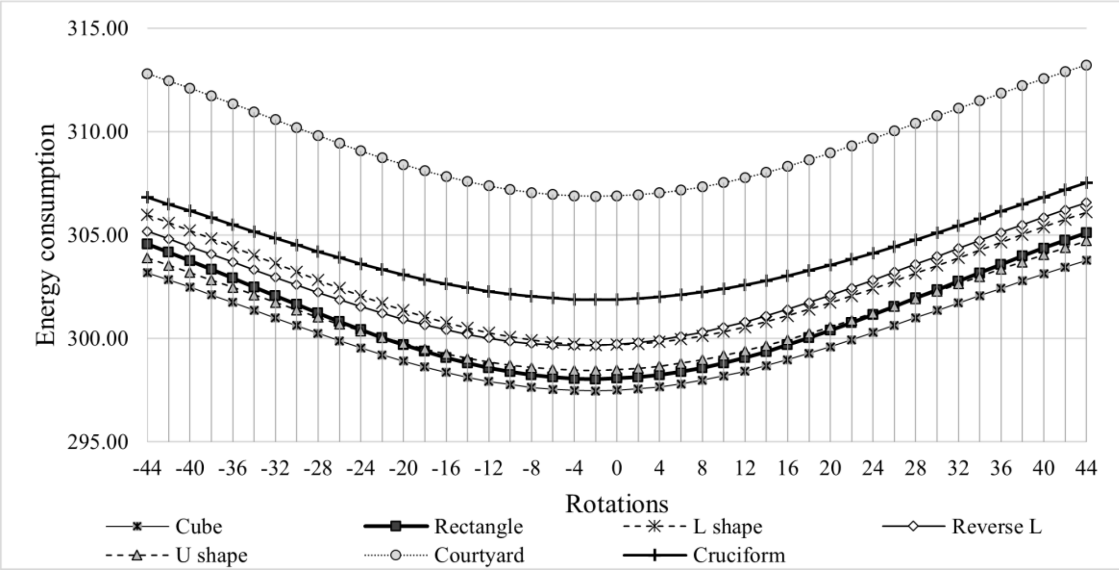


Chart 10: *Energy consumption of selected forms for Gorgan.*

Chart 10 shows that in Gorgan's humid climate, courtyard forms have the highest energy consumption (about 307–313 kWh/m²). Rectangles, L, reversed L, and U shapes have moderate use (minimum around 298–300 kWh/m² at 0° rotation), with U shapes benefiting from airflow that helps regulate humidity. Courtyard and cruciform have higher consumption due to greater surface area and poor humidity control, while central rotations (near 0°) generally minimize energy use by optimizing ventilation and limiting direct sun exposure. Extreme rotations increase energy consumption, showing the critical effect of orientation on ventilation and energy use in temperate, humid climates. Cubes have the lowest energy use in all rotations in this city.

Table 8: *Regression prediction equation for energy consumption for selected forms in Gorgan.*

Shapes	Regression Equation	R^2 Value
Cube	$y = 0.0032x^2 + 0.0109x + 297.8$	$R^2 = 0.9823$
Rectangle	$y = 0.0036x^2 + 0.0105x + 298.4$	$R^2 = 0.9833$
L-shape	$y = 0.0034x^2 + 0.0042x + 300.01$	$R^2 = 0.9845$
Reverse L-shape	$y = 0.0033x^2 + 0.0212x + 300.02$	$R^2 = 0.9831$
U-shape	$y = 0.0031x^2 + 0.0135x + 298.76$	$R^2 = 0.9847$
Courtyard	$y = 0.0033x^2 + 0.0083x + 307.19$	$R^2 = 0.9826$
Cruciform	$y = 0.0028x^2 + 0.0093x + 302.08$	$R^2 = 0.9913$

Table 8 demonstrates that energy use for building shapes in Gorgan can be accurately predicted by quadratic equations relating rotation angle *xx* to consumption, with all models showing excellent fit (R^2>0.98 R^2>0.98). The cube has the lowest baseline consumption (297.8), and the courtyard the highest (307.19); quadratic coefficients show energy use rises as rotation deviates from the optimum, and positive linear coefficients signal a slight increase with higher rotation angles. Compact shapes like cubes and U-shapes consistently have lower basic consumption, while courtyards and cruciform use more, but all forms are significantly impacted by orientation within Gorgan's climate.

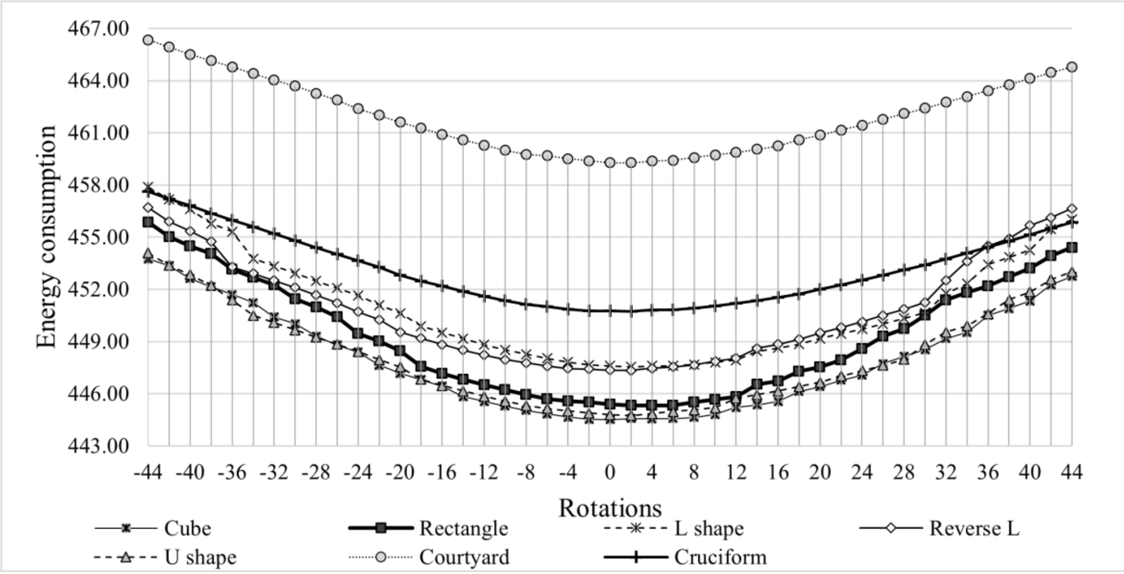


Chart 11: *Energy consumption of selected forms for Qeshm.*

Chart 11 reveals that in Qeshm's hot, humid climate, courtyard forms have the highest energy consumption (459–466 kWh/m²). Rectangles, L and reversed L forms, show moderate consumption and perform best at 0° rotation, optimizing airflow and minimizing direct sunlight. The courtyard and cruciform have higher energy use, reaching up to 450 kWh/m², due to greater heat and moisture exposure from larger surfaces. Energy use rises sharply with extreme rotations, underscoring the vital role of precise orientation for efficient cooling and ventilation in hot, humid conditions. Cubes and U forms have the lowest energy use in all rotations in this city.

Table 9: *Regression prediction equation for energy consumption for selected forms in Qeshm.*

Shapes	Regression Equation	R^2 Value
Cube	$y = 0.0047x^2 - 0.0181x + 444.77$	$R^2 = 0.9908$
Rectangle	$y = 0.0053x^2 - 0.0163x + 445.68$	$R^2 = 0.9845$
L-shape	$y = 0.0048x^2 - 0.028x + 447.72$	$R^2 = 0.9936$
Reverse L-shape	$y = 0.0049x^2$ - 7E-05$x + 447.48$	$R^2 = 0.992$
U-shape	$y = 0.0046x^2 - 0.0132x + 445.05$	$R^2 = 0.9946$
Courtyard	$y = 0.0033x^2 - 0.0187x + 459.69$	$R^2 = 0.9813$
Cruciform	$y = 0.0032x^2 - 0.0213x + 451$	$R^2 = 0.9892$

Table 9 indicates the energy consumption prediction equations in Qeshm for different building shapes, all of which show very high R^2 values (above 0.98), confirming the excellent accuracy of the model. The constant terms represent the baseline energy consumption, with the lowest value for the cube (444.77) and the highest value for the courtyard (459.69). The quadratic coefficients (x^2 terms) vary between 0.0032 and 0.0053 and show how energy consumption increases on average as the building's rotation deviates from the optimal angle. The negative linear coefficients (x terms) initially show a slight decrease in energy consumption with increasing rotation, before the quadratic effect causes consumption to increase. In general, cubic and U-shaped shapes tend to have lower baseline energy consumption, while more complex shapes, such as courtyards and cruciform shapes, start at higher values. The regression highlights the significant impact of building orientation on energy efficiency in all forms in hot and humid Qeshm.

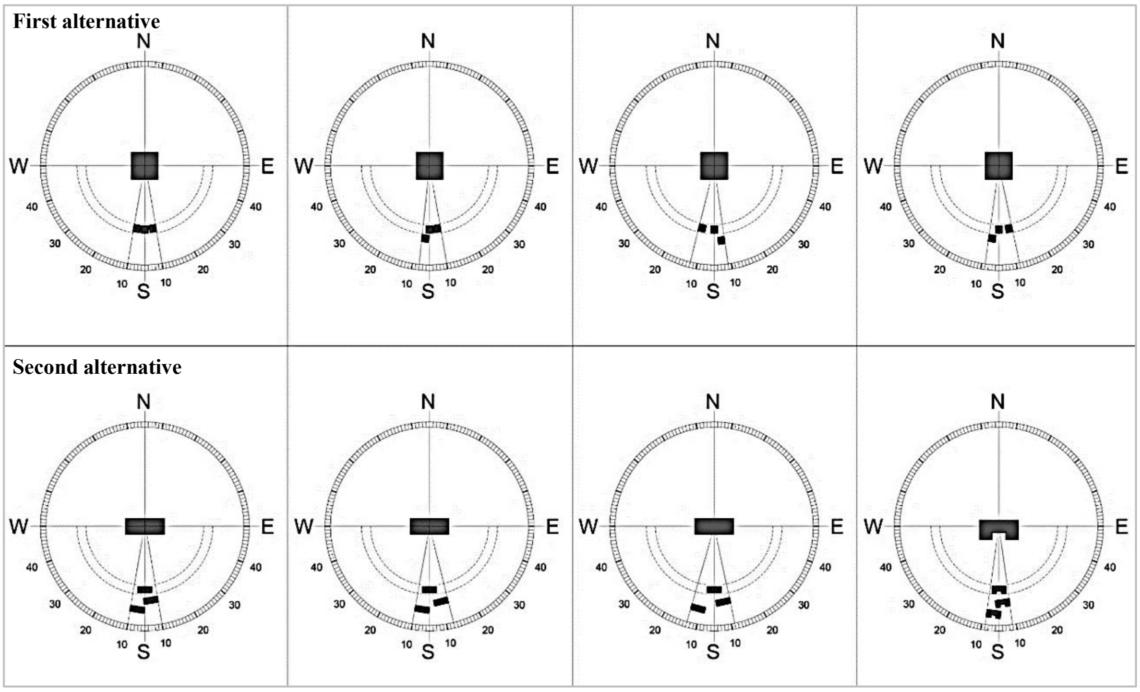


Chart 12: *Optimal form and direction in Shahrekord, Yazd, Gorgan, and Qeshm*.

Chart 12 presents two optimal designs for energy efficiency across Iranian cities: A square form with a slight east-southeast orientation (8°–14° east), typical rotations being about 10° in Shahrekord and Yazd, and 8°–14° in Gorgan and Qeshm. A rectangular form aligned east-west with similar eastward rotations, except in Qeshm, where a U-shaped form with rotations from 8° east to 8° west is optimal. Both designs leverage a subtle eastward orientation to reduce heat gain and enhance ventilation, tailored to each city's climate for minimizing energy consumption.

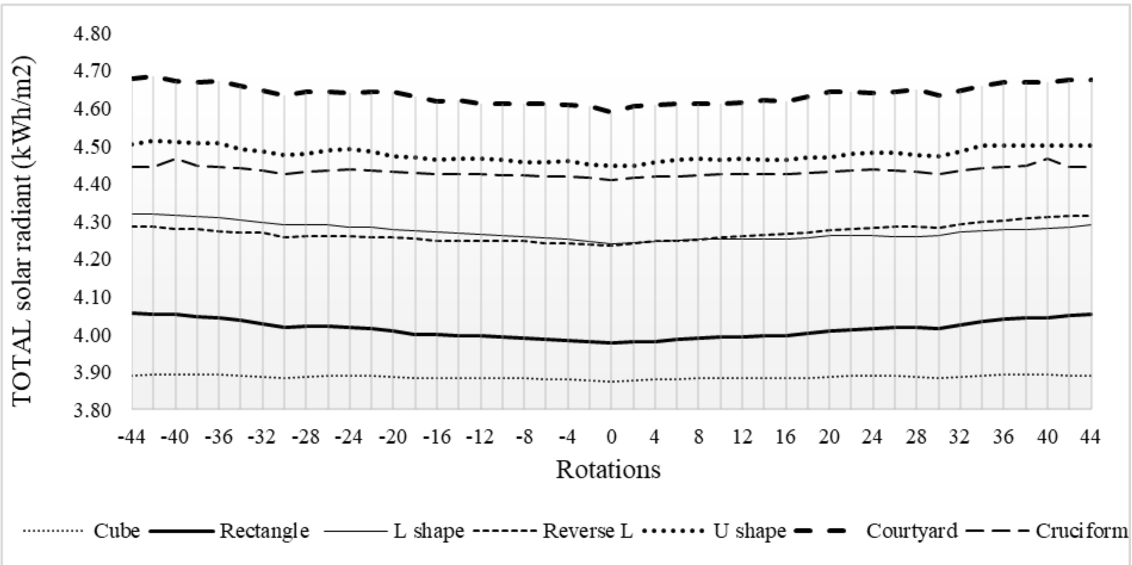


Chart 13: *Compare total solar radiation in different Shapes and Rotations in Shahrekord.*

Chart 13 indicates that in Shahrekord, the central courtyard form absorbs the most solar radiation (4.70 kWh/m²), about 20% more than cube forms; U and cross shapes absorb about 10% less than courtyards, while L and inverted L forms receive roughly 15% less. Building shape has a greater impact on solar gain than orientation, with rotation only causing minor changes. Courtyard and U-shaped plans are optimal for maximizing solar absorption, while cubes and L-shaped designs minimize it; thus, different forms and orientations should be selected depending on climate needs, maximizing solar gain in cold conditions or reducing it in hot climates.

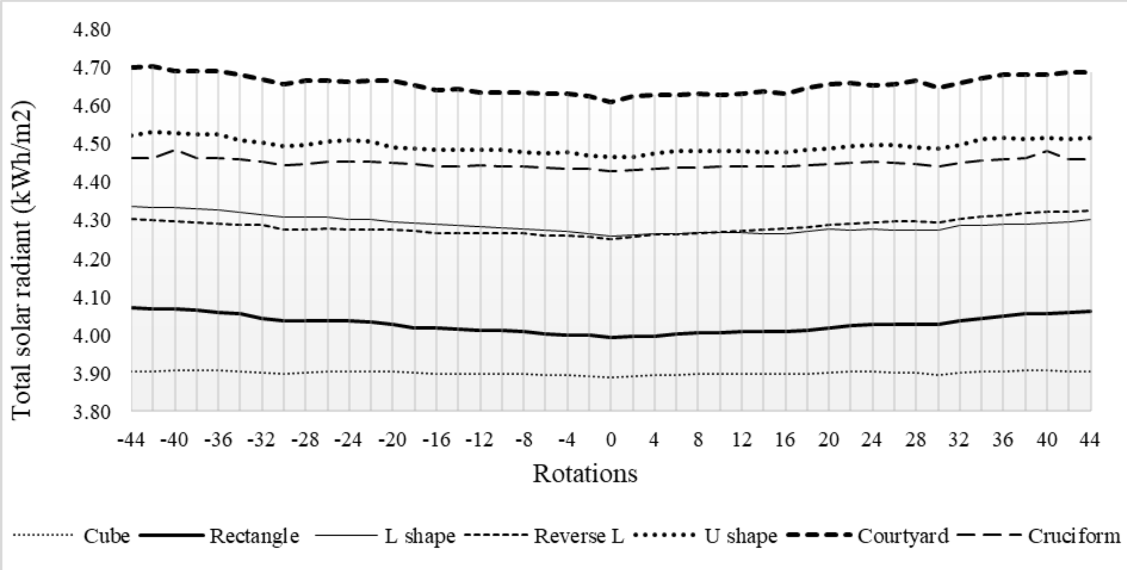


Chart 14: *Compare total solar radiation in different Shapes and Rotations in Yazd.*

Chart 14 illustrates that in Yazd, central courtyard shapes absorb the most solar radiation (4.65–4.75 kWh/m²), with cubes receiving 3.9 kWh/m², about 17% less. U and cross forms get roughly 10% less than courtyards, while L and inverted L designs receive 12–15% less. Thus, for hot areas like Yazd, courtyard and U shapes maximize solar absorption, but cube and L designs, with lower solar gain, offer better energy efficiency.

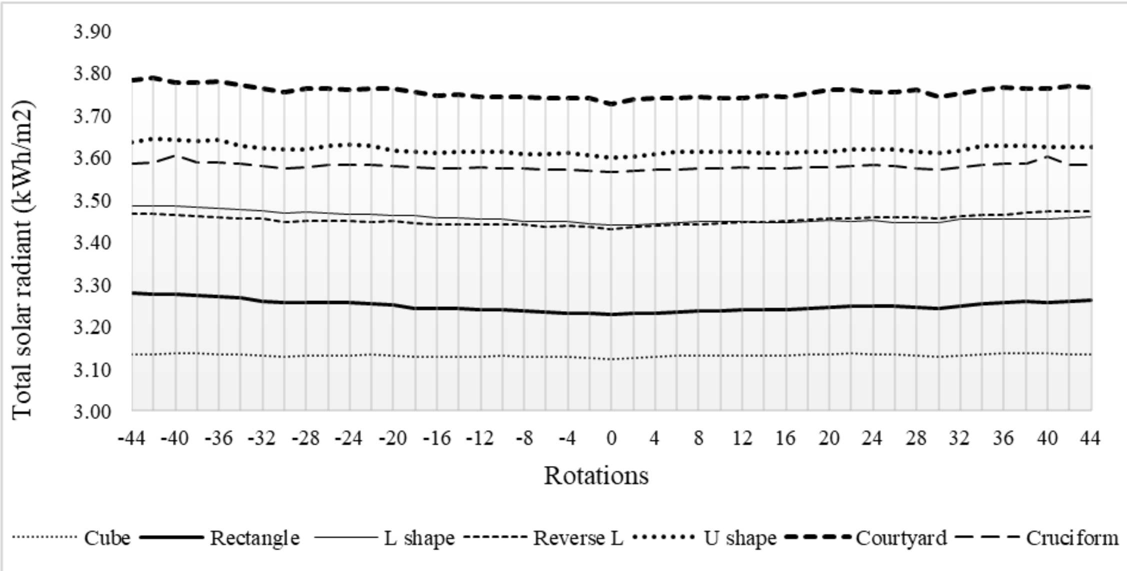


Chart 15: *Compare total solar radiation in different Shapes and Rotations in Gorgan.*

Chart 15 shows the total solar radiation for various building shapes in Gorgan with different rotations. In this city, the central courtyard form has recorded the highest radiation level, which is about 3.80 kWh/m^2, followed by the U and cross forms with about 9% less than that, and then the L and inverted L with about 13% less than the central courtyard. The cube has the lowest radiation of 3.15 kWh/m^2, about 17% less than the central courtyard. Finally, it has been found that the central courtyard and U forms are more suitable for absorbing the most energy from the sun in the climatic conditions of Gorgan.

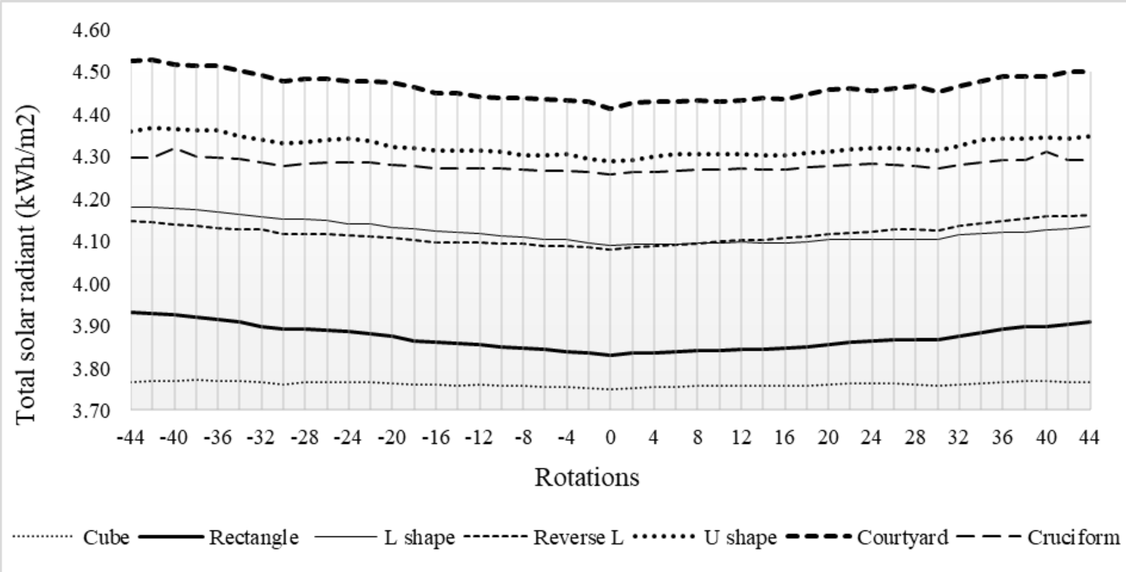


Chart 16: *Compare total solar radiation in different Shapes and Rotations in Qeshm.*

Chart 16 compares the total solar radiation received by different shapes at different rotation angles in Qeshm. The central courtyard shape consistently has the highest rad absorption, averaging about 4.45 kWh/m^2, which is 5% to 7% more than the cube and inverted L, which have the lowest values. The U, rectangle, L, and cross shapes are similar and have a difference of 2% to 4% in solar energy received from the central courtyard shape. The results show that choosing the right shape to best suit the climatic conditions of Qeshm is much more important than the rotation.

Discussion

From an annual energy consumption perspective, compact forms (cubic, L) consume 15-25% less energy than courtyards and U-shapes in all climates. However, in hot and humid climates such as Qeshm and Gorgan, courtyards offer microclimate and comfort benefits (shade, ventilation), although their annual energy consumption is still higher due to the increased surface area.

Secondly, the orientation and rotation of buildings are crucial for energy efficiency, especially in challenging climates; in cities like Yazd, Gorgan, and Qeshm, aligning with solar angles and prevailing winds enhances performance, while in Shahrekord, energy demand is lower and less dependent on form or orientation due to reduced cooling needs. Hot, dry climates require strategies to cut solar heat gain, and humid cities like Gorgan need careful ventilation and humidity control to optimize energy performance.

Overall, the research shows that integrating climate considerations with building form and orientation is essential for achieving high energy efficiency; cubic and L-shaped forms consistently perform well, so architects should prioritize these shapes and then optimize building orientation to further reduce energy use. Solar absorption varies significantly among building forms: courtyard and U-shaped designs receive up to 20% more solar radiation than compact cubes and L-shapes, which leads to higher cooling loads and energy use in hot climates. Compact forms balance minimal heat loss and optimized solar gain, making them more energy efficient overall. These results highlight the importance of integrating solar gain and energy consumption data when designing for climate; in cold regions like Shahrekord, more solar gain can help with heating, while in hot areas like Yazd and Qeshm, limiting solar absorption is crucial for energy savings. Link between solar absorption and energy use, in cold climates (Shahrekord), increased solar absorption has reduced heating energy. While in hot/humid climates, increased solar absorption has increased the cooling load and consequently increased the total energy consumption of the building.

Recommendation

Next, a heat map has been drawn to graphically present the results so that architects and energy designers can, in the shortest possible time, review these results and make a quick and efficient decision about the initial form of the designs, as well as the optimal direction of rotation, considering the weather conditions, and present it to employers. As shown in Figures 7-10, the heat maps outline energy use in Shahrekord, Yazd, Gorgan, and Ghesm buildings over a year, exhibiting the buildings in different orientations. A gradient from green (least) to yellow and red (most) illustrates energy consumption in a year. This visualization quickly illustrates how the design and orientation of a building within various weather conditions affect energy use efficiency. The optimum design configurations are highlighted in this visualization to streamline the analysis of building energy form and orientation

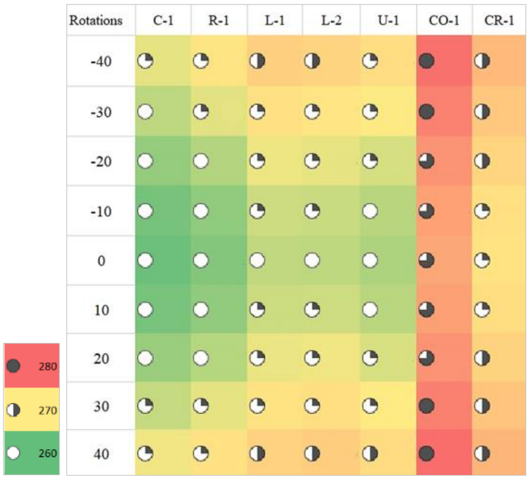


Figure 7: *Heat Map of Annual Energy Consumption for Different Building Forms and Rotations in Shahrekord*

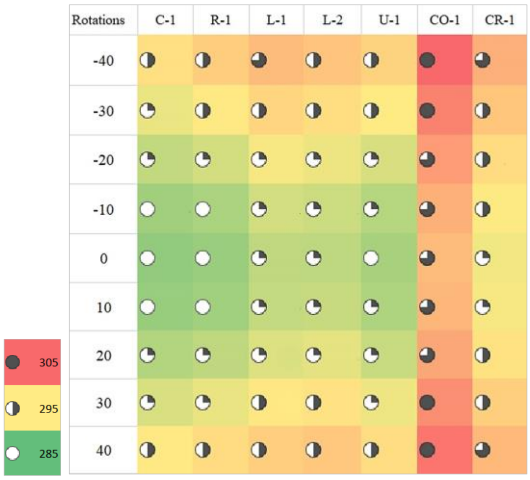


Figure 8: *Heat Map of Annual Energy Consumption for Different Building Forms and Rotations in Yazd*

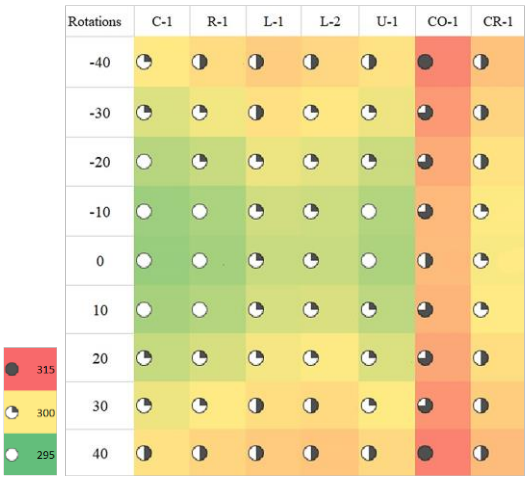


Figure 9: *Heat Map of Annual Energy Consumption for Different Building Forms and Rotations in Gorgan*

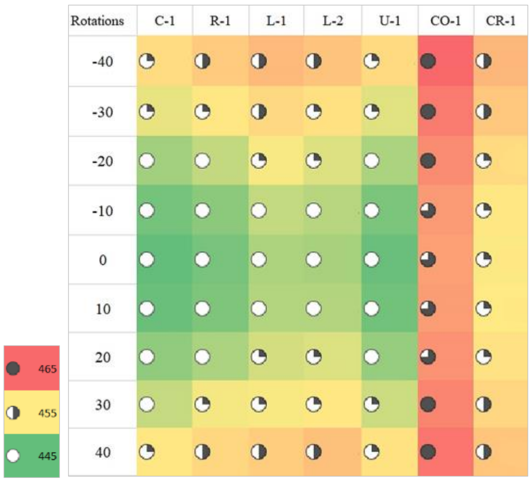


Figure 10: *Heat Map of Annual Energy Consumption for Different Building Forms and Rotations in Qeshm*

Conclusion

Buildings with cubic and L-shaped forms consumed an average of 3 to 4 percent less energy than central courtyard, U-shaped, and cruciform forms in all climates. In the cold climate of Shahrekord, the overall difference in energy consumption between the different forms was larger, and there was around a 6 percent difference between the lowest and highest energy-consuming forms. In warmer climates such as Yazd and Gorgan, the differences were smaller, and central courtyard and U-shaped forms consumed approximately 4 percent more energy than cubic and L-shaped forms, much of which was due to the higher cooling demand in these cities. The effect of building orientation in Yazd, Gorgan, and Qeshm was very significant, with the inverted L and central courtyard forms showing up to a 4 percent increase in energy consumption at inappropriate angles. While cubic and rectangular forms have less fluctuation. The overall comparison of cities based on energy consumption from lowest to highest is as follows: Shahrekord is considered the base energy consumption, and the rest of the cities are measured against it. Yazd is 10% more than Shahrekord, Gorgan is about 13% more than Shahrekord, and Qeshm is the most consumed, approximately 45% more than Shahrekord. The results show that climate and architectural form have a significant impact on the energy consumption of buildings. Optimizing the form and orientation of a building not only reduces total energy consumption but also optimizes solar energy absorption, which is especially important in Iran's different climates. Solar radiation studies showed that the central courtyard form absorbs about 20 percent more solar energy than the cubic form in all locations, but this increased absorption in warmer climates has led to increased energy consumption for cooling.

Table 10: *Summary of Minform and Maxform in each city.*

Location	Min form	Max form
Shahrekord	Cube	Courtyard
Yazd	Cube	Courtyard
Gorgan	Cube	Courtyard
Qeshm	Cube	Courtyard

Nomenclature

EUI	Energy Use Intensity
HVAC	Heating, Ventilation, and Air Conditioning
WWR	Window to Wall Ratio
2D	Two-Dimensional
3D	Three-Dimensional
EPW	EnergyPlus Weather
SHGC	Solar Heat Gain Coefficient
IEA	International Energy Agency
C-D	Cold and Dry
H-D	Hot and Dry
M-H	Moderate and Humid
H-H	Hot and Humid

References

Aleksandr Orishev, Azer Mamedov, Igor Yu Zalysin, Dmitry Kotusov, & Sergey Grigoriev. (2020). "The development of travel and tourism industry in Iran."

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2017). "ASHRAE Handbook — Fundamentals." In Atlanta, GA, USA: ASHRAE.

Arenhart, Rodrigo Schons, Tailon Martins, Renan Mitsuo Ueda, Adriano Mendonça Souza, and Roselaine Ruviaro Zanini. (2024). "Energy use and its contributors in hotel buildings: A Systematic Review and Meta-Analysis." *PLoS ONE, 19*(10): 1–27. https://doi.org/10.1371/journal.pone.0309745.

Asgar Khademvatani, Mohammad Naserifard. (1392). "Sectoral analysis of energy consumption in Iran." In *The 3rd International Conference of IEA*, ed. *Technology and Energy Management.*

Balali, Amirhossein, & Akilu Yunusa-Kaltungo. (2025). “Selection of passive energy consumption optimisation strategies for buildings.” *Renewable and Sustainable Energy Reviews* 210: 115222. https://doi.org/10.1016/j.rser.2024.115222.

Bijami, Maryam, & Albattat Ahmad. (2019). “Challenges in Iran Tourism Industry.” *Journal of Travel, Tourism and Recreation, 1*(1): 1–6. https://doi.org/10.22259/2642-908x.0101001.

Canbolat, Ahmet Serhan, & Emre İsa Albak. (2024). “Multi-Objective optimization of building design parameters for cost reduction and co2 emission control using four different algorithms.” *Applied Sciences, 14*(17). https://doi.org/10.3390/app14177668.

Carroll, & John. (2003). *Making Use: Scenario-Based Design of Human-Computer Interactions*. https://doi.org/10.7551/mitpress/4398.001.0001.

Chen, Ningjing, & Juanfen Wang. (2023). “Multi-Objective optimization of building planning energy saving based on genetic algorithm.” *Infrastructure Asset Management*: 1–14. https://doi.org/10.1680/jinam.23.00040.

Choi, Myeong-in, Byeongkwan Kang, Sanghoon Lee, Sangmin Park, Jun Seon Beck, Sang Hyeon Lee, & Sehyun Park. (2024). “Empirical study on optimization methods of building energy operation for the sustainability of buildings with integrated renewable energy.” *Energy and Buildings* 305: 113908. https://doi.org/10.1016/j.enbuild.2024.113908.

Climate.onebuilding.org. (2018). “EPW File.” https://climate.onebuilding.org/

Deng, Shiming, & John Burnett. (2002). “Energy use and management in hotels in Hong Kong.” *International Journal of Hospitality Management* 21: 371–80. https://doi.org/10.1016/S0278-4319(02)00016-6.

Edwin Rodriguez-Ubinasa, Claudio Montero, María Porterosa, Sergio Vega, Iñaki Navarro, Manuel Castillo-Cagigal, Eduardo Matallanas, & Alvaro Gutiérrez. (2014). “Passive design strategies and performance of net plus energy houses.” *Energy and Buildings*.

Elbeltagi, Emad, Hossam Wefki, & Rana Khallaf. (2023). “Sustainable building optimization model for early-stage design.” *Buildings, 13*(1). https://doi.org/10.3390/buildings13010074.

Emad Elbeltagi, Hossam Wefki, & Rana Khallaf. (2023). “Sustainable building optimization model for early-stage design.” *Building and Environment*.

F. Rashid, M. E. Hoque, K.I. Peash, F. & Faisal. (2017). “Performance analysis and investigation for the development of energy efficient building.” In *Proceedings of the International Conference on Mechanical Engineering and Renewable Energy 2017*, Chittagong, Bangladesh: ICMERE2017-PI-311 PERFORMANCE.

Flotation, & Dissolved. (2022). “Design guideline tourist accommodation facilities.” *Ministry of tourism and lands* (October): 1–71.

Gardezi, Syed Shujaa Safdar, Nasir Shafiq, Ishtiaq Hassan, & M. Usman Arshid. (2021). “Life cycle carbon footprint assessments, case study of malaysian housing sector.” *Environmental and Climate Technologies, 25*(1): 1003–17. https://doi.org/10.2478/rtuect-2021-0076.

Gössling, & Stefan. (2004). “10 tourism and water.” *Journal of Tourism Futures*.

H. Gholami, H. Kamelnia, M. J. Mahdavinejad, H. & Sangin. (2025). “Optimizing building configuration and orientation for social housing projects in Iran.” *Iranica Journal of Energy and Environment*.

Halwatura, Shakila Pathirana, Asanka Rodrigo, & Rangika. (2019). “Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate.” *International Journal of Energy and Environmental Engineering*.

Hamid Samami, Seyednima Naghibi Iravani, Seyyed Arash Sohrabi, Nima Gheitarani, & Dehghan Samad. (2024). "Evaluation and optimization of building greening methods in four different climates using Building Information Modeling (BIM)." *European Online Journal of Natural and Social Sciences*.

Hanlin Li, Yanping Yuan, Dan Wu, Yuhang Fan, & Fujian Jiang. (2024). "Optimizing of architectural geometry and tubular daylight guidance system based on genetic algorithm to enhance daylighting and energy performance in underground office buildings." *Journal of Building Engineering*.

Hassan, Akbari, & Hosseini Nezhad Fatemeh Sadat. (2019). "The angles of building orientation for solar energy use; A case study of Tehran city, Iran." *Geographical Research Quarterly Journal, 34*(3), 427–36. https://doi.org/10.29252/geores.34.3.427.

Hassan Akbaria, & Fatemeh Sadat Hosseini Nezhad. (2020). "Optimum form, aspect ratio and orientation of building based on solar energy receiving in hot-dry climate; Case studies of Isfahan, Semnan, Kashan and Kerman cities, Iran." *Journal of Solar Energy Research*.

Highlights, International Tourism. (2023). "UNWTO (World Tourism Organization)." https://www.unwto.org/international-tourism-highlights.

Hu, Shushan, Hoare, Cathal, Raftery, Paul, O'Donnell, & James. (2019). "Environmental and energy performance assessment of buildings using scenario modelling and fuzzy analytic network process." *Research Repository UCD*.

Jie Xiong, Siyue Guo, Yi Wu, Da Yan, Chan Xiao, & Xi Lu. (2023). "Predicting the response of heating and cooling demands of residential buildings with various thermal performances in China to climate change." https://doi.org/10.1016/j.energy.2023.126789.

Jin, Jeong Tak, & Jae Weon Jeong. (2014). "Optimization of a free-form building shape to minimize external thermal load using genetic algorithm." *Energy and Buildings, 85*, 473–82. https://doi.org/10.1016/j.enbuild.2014.09.080.

Jin Li, Chao Liang, & Wenwu Zhou. (2024). "A Review of building physical shapes on heating and cooling energy consumption." *energies*.

Jin Zhan, Wenjing He, & Jianxiang Huang. (2024). "Comfort, carbon emissions, and cost of building envelope and photovoltaic arrangement optimization through a two-stage model."

Karoline Brucke, Stefan Arens, Jan-Simon Telle, Sunke Schlters, Karsten von Maydell, Carsten Agert, & Benedikt Hanke. (2020). "Particle swarm optimization for energy disaggregation in industrial and commercial buildings."

Kasmae, & Morteza. (2003). Climate and Architecture. *Second. ed. Mohammad Ahmadinejad.*

Ke Liu, Xiaodong Xu, Wenxin Huang, Ran Zhang, Lingyu Kong, & Xi Wang. (2023). "A multi-objective optimization framework for designing urban block forms considering daylight, energy consumption, and photovoltaic energy potential." *Building and Environment*.

Khodadadi, & Masood. (2016). "Challenges and opportunities for tourism development in iran: perspectives of Iranian tourism suppliers." *Tourism Management Perspectives, 19*, 90–92. https://doi.org/10.1016/j.tmp.2016.05.001.

Konis, Kyle, Alejandro Gamas, & Karen Kensek. (2016). "Passive performance and building form: an optimization framework for early-stage design support file." *Solar Energy,* 125, 161–79. https://doi.org/10.1016/j.solener.2015.12.020.

Kubwimana, Benjamin, & Hamidreza Najafi. (2023). "A novel approach for optimizing building energy models using machine learning algorithms." *Energies, 16*(3). https://doi.org/10.3390/en16031033.

Lai Wei, Wei Tian, Jian Zuo, Zhi-Yong Yang, YunLiang Liu,& Song Yang. (2016). "Effect of building form on energy use for buildings in cold climate regions." *Procedia Engineering*.

Lapisa, & Remon. (2019). "The effect of building geometric shape and orientation on its energy performance in various climate regions." *International Journal of GEOMATE*.

Lechner, & Norbert. (2008). Heating, cooling, lighting: Sustainable design methods for architects. *3rd ed. John Wiley & Sons Inc.*

Leon Wu, Gail Kaiser, David Solomon, Rebecca Winter, Albert Boulanger, & Roger Anderson. (?). "Improving efficiency and reliability of building systems using machine learning and automated online evaluation." *CORE Provided*.

der Linden, Valerie, Hua Dong, & Ann Heylighen. (2019). "Populating architectural design: introducing scenario-based design in residential care projects." *International Journal of Design, 13*, 21–36.

Longwei Zhang, Chao Wang, Yu Chen,& Lingling Zhang. (2021). "Multi-Objective optimization method for the shape of large-space buildings dominated by solar energy gain in the early design stage." *Frontiers in Energy Research*.

Mahdavinejad, & Reza Fallahtafti Mohammadjavad. (2015). "Optimisation of building shape and orientation for better energy efficient architecture." *International Journal of Energy Sector Management*.

Mahsa Torabi, & Ralph Evins. (2023). "Evaluating building carbon footprint in concept design stage." In *International Building Performace Simulation Association*, Conference Paper · September 2023.

Manmatharasan, Piragash, Girma Bitsuamlak, & Katarina Grolinger. (2025). "AI-Driven design optimization for sustainable buildings: A systematic review." *Energy and Buildings* 332 (February): 115440. https://doi.org/10.1016/j.enbuild.2025.115440.

Ministry of Roads, Urban Development, Building, & Housing Research Center. (2021). Iranian national building regulations, topic 19: Energy conservation. 4th ed. *Tehran, Iran: Office for Compilation of National Building Regulations.*

Mohammad Ebadollahi, & Majid Amidpour. (2023). "Trend of energy production and consumption in iran by predicting the state of renewable energy in the horizon of 2040." *Electromechanical Energy Conversion Systems*.

Mohammadjavad Mahdavinejad, Hassan Bazazzadeh, Fatemeh Mehrvarz, Umberto Berardi e, Tahereh Nasr f, Somayeh Pourbagher b, & Siamak Hoseinzadeh g. (2024). "The impact of facade geometry on visual comfort and energy consumption in an office building in different climatesthe impact of facade geometry on visual comfort and energy consumption in an office building in different climates." *Energy Reports*.

Murat Altun, & Asli Akcamete-Gungor. (2015). "BIM-based multi-objective building life cycle energy performance evaluation using particle swarm optimization murat." In *The 32nd CIB W78 Conference 2015, 27th-29th 2015*, *Eindhoven, The Netherlands.*

Na Zhao, Jia Zhang, Yewei Dong, & Chao Ding. (2024). "Multi-Objective optimization and sensitivity analysis of building envelopes and solar panels using intelligent algorithms." *Buildings*.

Negendahl, & Kristoffer. (2015). "Building performance simulation in the early design stage: An introduction to integrated dynamic models." *Automation in Construction, 54*, 39–53. https://doi.org/10.1016/j.autcon.2015.03.002.

O Donnell, James, Marcus Keane, Elmer Morrissey, & Vladimir Bazjanac. (2013). "Scenario modelling: A holistic environmental and energy management method for building operation optimisation." *Energy and Buildings, 62*, 146–157. https://doi.org/10.1016/j.enbuild.2012.10.060.

Payam Soltan Ahmadi, Ahmad Khoshgard, & Hossein Ahmadi Danesh Ashtiani. (2025). “The impacts of residential buildings’ energy compliance standards on Iran’s GHG emissions toward achieving the paris agreement.” *Journal of Engineering Research*.

Rong Li, Zalina Shari, & Mohd Zainal Abidin Ab Kadir. (2025). “A review on Multi-Objective optimization of building performance - insights from bibliometric analysis.” *Heliyon*.

Roudsari, Mostapha Sadeghipour, & Michelle Pak. (2013). “Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design.” *Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association* (January 2013): 3128–35. https://doi.org/10.26868/25222708.2013.2499.

Salvalai, Graziano, Gabriele Masera, & Marta Maria Sesana. (2015). “Italian local codes for energy efficiency of buildings: theoretical definition and experimental application to a residential case study.” *Renewable and Sustainable Energy Reviews, 42,* 1245–59. https://doi.org/10.1016/j.rser.2014.10.038.

Seddik Hassan, Ahmed M., Reham Fathy Ahmed Abd El Aal, Asmaa Abd Elmoneim Fahmi, Sherif Mohamed Ahmed Ali, & Mohamed I.M. Abdelhady. (2024). “Courtyard geometry’s effect on energy consumption of Alkharga city residential buildings, Egypt.” *Scientific Reports, 14*(1), 1–18. https://doi.org/10.1038/s41598-024-60487-8.

Sharifabadi, Morovati, & Ardakani Asadian. (2014). “A model for health tourism development using fuzzy topsis and interpretive structural modeling in Yazd province.” *Journal of Health Administration, 17*(55), 73–88. https://jha.iums.ac.ir/article-1-1458-en.html (June 5, 2025).

Shorabeh, Saman Nadizadeh, Najmeh Neysani Samany, Foad Minaei, Hamzeh Karimi Firozjaei, Mehdi Homaee & Ali Darvishi Boloorani. (2022). “A decision model based on decision tree and particle swarm optimization algorithms to identify optimal locations for solar power plants construction in Iran.” *Renewable Energy, 187,* 56–67. https://doi.org/10.1016/j.renene.2022.01.011.

Stasi, Roberto, Francesco Ruggiero, & Umberto Berardi. “Influence of building shape on cross-ventilation cooling potential of high-rise buildings in a hot and humid climate.”

Straube, & John. (2012). “The function of form: Building shape and energy.” *Insight, Building Science*. 1–F4.

T Shao, & H Jin. (2019). “The impact of rural houses’ orientation on heating energy consumption in severe cold regions of China.” In *Earth and Environmental Science*, *9th International Conference on Future Environment and Energy,* 257.

Vassiliades, C. (2024). “Optimizing energy efficiency in Mediterranean single-family homes: a parametric study of building typology, orientation, and BIPV integration.” *Renewable Energy*.

Yang, Teng, Wanxiang Yao, Ting Lei, Jinfu Cao, & Bart Julien Dewancker. (2025). “Study on the impact of land-sea distribution on future building energy consumption in Chinese cities under the background of climate change.” *Energy and Buildings, 332*, 115434. https://doi.org/10.1016/j.enbuild.2025.115434.

Yun Kyu Yi, Ali M., & Malkawi. (2009). “Optimizing building form for energy performance based on hierarchical geometry relation.” *Automation in Construction*.

Zhong, Xiaoyang, Mingming Hu, Sebastiaan Deetman, Bernhard Steubing, Hai Xiang Lin, Glenn Aguilar Hernandez, Carina Harpprecht, et al. 2021. “Global Greenhouse Gas Emissions from Residential and Commercial Building Materials and Mitigation Strategies to 2060.” *Nature Communications* 12(1): 6126. doi:10.1038/s41467-021-26212-z.

Zolfaghari, Hasan. (2025). “Potential and limitations in Iran for developing tourism sector.” *International Symposium on Geography, Environment and Culture in the Mediterranean Region*.